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UNITED STATES
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HYDRAULIC MODEL STUDIES OF GLENDO DAM OUTLET WORKS--MISSOURI RIVER BASIN PROJECT WYOMING

Hydraulic Laboratory Report Hyd-461

DIVISION OF ENGINEERING LABORATORIES

COMMISSIONER'S OFFICE
DENVER, COLORADO

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Hydraulic Laboratory Branch
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Subject: Hydraulic model studies of Glendo Dam outlet works--Missouri River Basin Project, Wyoming

PURPOSE

The model studies were conducted to investigate the causes of the cavitation erosion in the stilling basin and to develop the necessary corrective measures to eliminate the cavitation erosion on the flow surfaces.

CONCLUSIONS

1. The 1:18.4 scale model of one bay was adequate to study the pressures along the flow surfaces and the sweepout conditions in the outlet works stilling basin.

2. Excessive wall divergence just downstream from the control gates caused the cavitation erosion along the flared walls, Figure 2A. Installation of the air-admission equipment with seven 2-inch drilled holes and a 2-1/2 inch by 10-inch opening as vents, Figure 3, will eliminate the cavitation erosion in the upstream portion of the flared walls.

3. The cavitation erosion in and downstream for the stoplog slots, Figure 2A, will be eliminated by filling the slots with concrete.

4. Severe cavitation on the chute blocks was caused by insufficient streamlining of the block surfaces. Pressure studies indicated that the installation of Chute Block 5, Figure 8, will eliminate the cavitation on the chute blocks.

5. At gate openings above 50 percent and certain tail-water elevations, cavitation erosion may occur on the stilling basin floor immediately downstream from the chute blocks, Figure 14. No practicable method of relieving this low-pressure region was determined from the model studies.

6. Although no cavitation erosion was detected on the prototype baffle piers after the 1958 irrigation season, the study indicated that cavitation may occur on the sides of the pier at near maximum discharges. The streamlining, Pier 6, Figure 16, is adequate to prevent cavitation on the surfaces of the baffle piers at all operating heads and gate openings.

7. The installation of the air-admission equipment and streamlining the chute blocks and baffle piers reduced the stability of the hydraulic jump.

8. Under existing tail-water conditions and with the reservoir surface at the top of the flood pool, or elevation 4753 feet: (a) the outlet works stilling basin will safely handle the design discharge of 10,000 second-feet when the powerplant is operating; (b) a combined flow of 10,700 second-feet can be released through one power unit and the outlet works without the jump sweeping out; and (c) with no flow through the powerplant, the jump will sweep out when the outlet works discharge exceeds 8,000 second-feet.

9. With the reservoir surface at elevation 4640 feet and no flow through the powerplant, the jump will sweep out when the outlet works discharge exceeds 9,200 second-feet under tail-water conditions existing in 1959.

10. Model pressure measurements in the stilling basin were inconclusive in establishing the source of the thumping and related vibrations in the structure. Sufficient pressure variations to induce vibration were measured along the training wall.

11. Modifications of the chute blocks and baffle piers, as determined from this study, will have no adverse effect on the erosion in the outlet channel.

ACKNOWLEDGEMENT

The testing and development program discussed in this report reflects the cooperative efforts of the Dams Branch, the Mechanical Branch, and the Hydraulic Laboratory Branch of the Commissioner's Office, Denver, Colorado.

INTRODUCTION

Glendo Dam is located on the North Platte River about 30 miles northwest of Guernsey, Wyoming. The intake of the outlet works is located about one-half mile upstream from the dam and by making use of a "hairpin" bend in the river flow from the outlet works and powerplant enters the river channel about 3 miles downstream from the dam. The circular outlet conduit supplies water to both the powerplant and outlet works which adjoin each other and discharge into a common outlet channel, Figure 1. The outlet works with a designed capacity of 10,000 second-feet is controlled by three regulating slide gates, each 7 feet 3 inches wide and 7 feet 9 inches high. The powerplant has two generating units with a total discharge capacity of 3,400 second-feet under full generating load.

Construction of Glendo Dam was completed in 1957 and water storage started in October. Releases through the outlet works began in April 1958 and ranged between 4,000 and 5,500 second-feet during July. Turbines were being installed in the powerplant, so no powerplant releases were made during 1958.

When the outlet works was first placed in operation, an audible, periodic thump was noted in the stilling pool at certain gate openings and vibrations could be felt in the basin training walls and the walls of the powerhouse. 1/ In July when the discharge was increased to about 5,000 second-feet, the thumping and vibration became more pronounced and the top of the left training wall was observed to deflect about 1/8 inch. On July 22, the outlet works was shut down and a diver inspected the flow surfaces in the stilling basin. This inspection disclosed evidence of cavitation erosion at the beginning of the flared walls immediately downstream from the control gates, in the stoplog slots in the flared walls, and on the sides of the center chute block in Bay 3. 2/ During the remainder of the irrigation season, releases were made through Gates 1 and 2 with Gate 3 closed.

In October, the basin was unwatered and a detailed inspection of the flow surfaces disclosed extensive cavitation erosion in the flared walls, at the bottom of the stoplog slots, and along the sides of the center chute block in Bays 1 and 2, Figure 2. 3/ No evidence of cavitation was found on the baffle piers or at any construction joints.

The extensive damage in the flow surfaces at the flared walls and on the chute blocks required immediate corrective measures to prevent further deterioration of the surfaces by cavitation. A hydraulic model was constructed and tested to determine the cause of the cavitation and to develop the necessary corrective measures.

This report discusses the results of that model study.

THE MODEL

The studies were conducted on a 1:18.4 scale model of the outlet works and downstream river channel, Figures 1 and 22A. Because of fund and time limitations, only one of the three bays was made operative. An existing gate was modified and installed in Bay 1, and the flow conditions for 3-bay operation were represented by extending the dividing wall between Bays 1 and 2 to the sill at the end of the basin, thus forming a line of symmetry at the left edge of Bay 1.

Three-bay operation was represented in the 1-bay model by releasing one-third of the basin discharge through the model gate in Bay 1 and setting the

1/ Travel Report "Inspection of Bonnet Cover Leakes in the 7.25- by 7.75-foot outlet gates--Glendo Dam," April 29, 1958, by Warren Kohler.
2/ Travel Report "Inspection of Glendo Dam Outlet Works Stilling Basin--Glendo Dam," August 27, 1958, by R. W. Whinnerah and W. E. Wagner.
3/ Travel Report "Examination of Outlet Works Stilling Basin--Glendo Dam," November 3, 1958, by M. A. Jabara.

tail water for the total basin discharge. Sweep-out data obtained from the 1-bay model check reasonably close the operation of the prototype and the results of the previous model study with three operating bays. Therefore, this isolating 1-bay model was considered adequate to study the pressure conditions along the flow surfaces and the sweep-out characteristics of the stilling basin for 1- and 3-bay operation.

THE INVESTIGATION

General

The inspection of the prototype flow surfaces indicated three regions of cavitation damage that required corrective measures: the flow surfaces along the flared walls, those in vicinity of the stoplog slots, and those on the sides of the chute blocks. During the study, a fourth region of probable cavitation damage was found along the sides of the baffle piers. This condition was aggravated by changes in shape and streamlining of the chute blocks.

These four regions of low pressure were investigated more or less simultaneously during the study. For presentation in this report, however, each is discussed separately.

Extensive pressure data were recorded from piezometer taps placed in critical regions of the flow surfaces. Single-leg water manometers were used to obtain the average pressure at the piezometer taps. When the average pressure reading indicated pressures near the cavitation range, a dynamic pressure transducer and Sanborn recorder were used to measure and record the pressure variations. From these recordings, the maximum and minimum "instantaneous" pressures were obtained.

Several reservoir elevations were used in investigating the structure. Early in the study, the tests were conducted using heads comparable to the maximum reservoir elevation of 4669 feet. Between reservoir elevations 4653 and 4669 feet, the uncontrolled spillway will operate and considerably more tail water will be available at the outlet works which would change the flow characteristics of the stilling basin. Later in the study, reservoir elevation 4653 feet (top of flood storage) was used because this elevation is the maximum head at which the outlet works will operate without additional tail water from the spillway. Several studies also were conducted using reservoir elevations of 4625 and 4635 which were the representative operating heads during the 1958 and 1959 irrigation seasons.

Reports on the operation of the prototype structure have indicated that comparatively small changes in tail water elevation affects the performance of the stilling basin. Consequently, many of the tests were made at tail-water elevations other than normal. The tail water used for a particular test is referred to normal tail-water elevation, which for the purpose of this study is 1 foot below the tail-water curve used in design, Figure 23. The tail-water curve existing in 1959 falls slightly above the "normal" tail-water elevations used in this study.

Flared Walls

To eliminate the cavitation erosion in the flared walls immediately downstream from the gate, it was proposed prior to the model studies that air-admission equipment with a 2-1/2-inch by 10-inch opening at the base of a 3-1/2-inch offset be installed at the upstream end of the flare in Figure 3. Tests were conducted both with and without this proposed venting system installed in the model.

With the structure as originally constructed (no air vents), average pressures equivalent to 30 feet of water below atmospheric were observed at piezometers placed immediately downstream from the start of the flared walls and 9 and 37 inches prototype above the chute floor, Figure 4. When the air-admission equipment (2-1/2-inch by 10-inch opening only) was installed, the minimum average pressure as measured by water manometers was 5 feet below atmospheric immediately downstream from the air vent, and the minimum instantaneous pressure measured by pressure cell was 12 feet below atmospheric, Table 1A. The vents took air at all gate openings and discharges; however, the demand for air was greater when the jet from the gate was submerged.

These tests indicated that the 2-1/2-inch by 10-inch opening was adequate to eliminate the cavitation erosion along the wall at the level of the opening. It was believed that the offset, with air supplied near the floor, would permit sufficient circulation of air to relieve any cavitation pressures above the opening. The air-admission equipment with the 2-1/2- by 10-inch opening, therefore, was installed in the structure early in 1959.

Sustained outlet works releases up to a maximum of 7,000 second-feet at reservoir elevations between about 4,595 and 4,625 feet were made during the 1959 irrigation season. The powerplant was discharging up to 3,600 second-feet which raised the available tail water and submerged the jets during these releases. In October 1959, the stilling basin again was unwatered. Cavitation damage, 14 to 25 inches above the chute floor, was found along the flared walls, Figure 5. Most of the releases were made at gate openings between 10 and 24 inches, indicating that the cavitation occurred in the vicinity of the interface between the high-velocity jet and the backwater from the stilling basin.

When it was learned that the 2-1/2- by 10-inch opening was insufficient to eliminate the cavitation above the opening, additional model tests were conducted with six circular holes spaced above the opening (see sketch in Table 2). Tests were conducted with the original 2-1/2- by 10-inch opening, with six 1-1/2-inch circular holes drilled on 3-inch centers above the opening, and with the six 1-1/2-inch holes enlarged to 2 inches. Pressures observed with these vent arrangements are shown in Table 2.

The 6 additional vents placed above the 2-1/2- by 10-inch opening helped the pressure conditions along the flared walls. The 2-inch holes, which were the largest circular vents that could be placed in the offset, gave higher pressures than the 1-1/2-inch holes. The instantaneous pressures using the 2-inch vents, however, still indicated possible cavitation at Piezometer 8 for 20 percent gate opening and at Piezometer 9 for 25 percent gate opening. It was decided to reduce the spacing of the vents from 3 to 2-1/2 inches between centers and provide seven vents in the same vertical distance, Figure 3. This vent arrangement, which was not tested in the model, provided the largest vent area consistent with adequate structural support for the air duct and was chosen for installation in the field.

Figure 2 contains representative oscillograph records of pressures recorded at critical piezometers with one 2-1/2- by 10-inch vent installed as compared to an arrangement of one 2-1/2- by 10-inch vent and six 2-inch holes.

Stoplog Slots

Two piezometers were installed in the vicinity of the stoplog slots, Figure 4, where cavitation erosion occurred in the prototype. Limited model tests indicated no cavitation pressures at these piezometers. No additional piezometers were installed to pinpoint the cause of the cavitation in the prototype, because the modifications to the structure included forming a continuous surface along the flared walls by filling the existing grooves with concrete which would eliminate any cavitation tendencies in this area.

Chute Blocks

Average pressures observed on the original chute block indicated cavitation would occur near the spring point of the elliptical curve at gate openings above 50 percent and reservoir elevation 4653 feet (top of flood storage), Table 3A. Instantaneous pressures measured at other piezometers indicated a still larger cavitation region in the vicinity of the spring point.

In developing satisfactory chute blocks for the basin, it was desirable that two design requirements be met: (1) the block surface must be free of cavitation, and (2) the effectiveness of the stilling basin should not be impaired. In general, these two requirements oppose each other; that is, additional curvature on the sides of the blocks is normally needed to raise the pressures, and increased curvature reduces the effectiveness of the block in deflecting the high velocity jet and stabilizing the hydraulic jump.

Seven chute block designs were tested and varied in height (2.9 to 7 feet), in width (5 to 7 feet), in slope of the block top, and in curvature of the sides of the block.

In general, the tests showed that the original block (7 feet high with upward slope) was best in stabilizing the hydraulic jump but gave the lowest pressures on the block surface. Improved pressures were obtained by increasing the curvature of the sides of the original block, but the improvement was insufficient to insure cavitation-free block surfaces. The upward slope was then removed from the original block making a block about 2.9 feet high; this shorter block caused large boils of water to form above the baffle piers and more tail water was required to hold the jump in the basin. Next, a block with horizontal top and 4 feet 7 inches in height was tested, and the basin performance was similar to that with the original block installed.

The preliminary tests indicated that the chute block should be at least 4-1/2 feet in height, but the test results were inconclusive in establishing that a block with an upward slope gave a better jump than the one with a horizontal top. Therefore, it was decided to develop a block with a horizontal top and a height such that the top of the block intersected the chute floor at a point 2 feet downstream from the contraction joint at Station 30+46, Figure 1. Tests of several variations of this basic design were conducted, including blocks with parallel sides, tapered sides to conform with the diverging flow, and with widths of 5 and 7 feet. The test results indicated little preference among the various shapes as far as jump performance was concerned. Although no pressure tests were conducted on the various shapes, a block with tapered sides was chosen for detailed pressure tests since a flow surface that is parallel to or encroaching on the flow lines generally requires less stream lining than one diverging away from the direction of flow.

The sides of the tapered block (Chute Block 5) were streamlined with a 5:1 elliptical curve in the direction of flow or parallel to the chute floor, Figure 8. Average pressure observations recorded for 25 to 100 percent gate openings, reservoir elevation 4653, and normal tail water are shown in Figure 9. The lowest average pressure observed on the block was about 4.6 feet of water below atmospheric at Piezometer 21 located on the downstream end of the block. About 4.4 feet below atmospheric at 83 percent gate opening was the lowest average pressure observed on the sides of the block. The lowest instantaneous pressure with normal tail water occurred at 50 percent gate opening and reached about 10 feet below atmospheric at Piezometer 4 on the side of the block and at Piezometer 21 on the downstream end of the block, Table 4. It is interesting that the lowest average pressure occurred at 83 percent gate opening while the lowest instantaneous pressure was observed at 50 percent gate opening. This apparent inconsistency was due to the position of the hydraulic jump in the basin; at 83 percent gate opening, the jump was practically swept from the basin, and the chute block was free of backwater from the jump; at 50 percent gate opening the jump roller extended upstream completely covering the chute block, and the surges inherent in the jump roller caused large pressure fluctuations on the block surface.

Average and instantaneous pressures also were recorded for various gate openings with the tail water elevation 1.5 and 3.0 feet above normal, Table 4. In general, slightly higher average pressures were observed with the higher tail water elevations. The instantaneous pressure, however, generally was lower with the increased tail water for the reasons stated above. The lowest instantaneous pressure observed on the chute block was 17 feet below atmospheric at Piezometer 3 at 50 percent gate opening and tail water 1-1/2 feet above normal. Slightly lower pressures were observed at Piezometer 25 in the floor downstream from the block; these are discussed under "Basin Floor Pressures."

On the basis of the above block tests, Chute Block 5, Figure 8, was chosen for construction in the prototype. Plots of the average pressures observed on Chute Block 5 for gate openings of 25, 50, 75, 83, and 100 percent and different tail water elevations is shown on Figure 9. Figures 10 and 11 show a comparison of the variations in pressure for the original and recommended chute block at gate opening of 60 and 83 percent and normal tail water.

Basin Floor Pressures

Piezometer 25 located on the basin floor, Figure 8, indicated that a low-pressure region existed immediately downstream from the chute blocks. To determine the extent of this low-pressure region, tests were conducted with 12 piezometers placed in the basin floor, Figure 12. The average pressure pattern for different gate openings and tail-water elevations is shown in Figure 13. The lowest average pressures were observed at 100 percent gate opening and normal tail water. Increasing the tail-water elevation 1-1/2 and 3 feet had the effect of increasing the average floor pressures at all gate openings.

Table 6 contains the average and instantaneous floor pressures recorded downstream from the original and recommended chute block for various gate openings and tail-water elevations. These test results indicate that changing the stream lining and size of the chute block slightly increased the instantaneous pressures on the floor downstream from the block. Although the average pressures generally increased with higher tail-water elevations, the minimum instantaneous pressure became lower as the tail-water elevation was increased. Thus, the higher tail water apparently changed the vortex flow pattern and increased the pressure variations downstream from the blocks. The minimum pressures at Piezometers 2, 11, and 12 were within the cavitation range at all gate openings above 50 percent, Table 6. Recordings of instantaneous pressures at representative piezometers for 50 percent gate opening and normal tail water is shown in Figure 14.

Various accessories were placed in the basin in an attempt to relieve the low pressures downstream from the block. These included 6- to 24-inch-high vertical steps between the chute blocks at Station 30+75.72, Figure 1; 3.6-foot-high extension walls at the block sides and downstream from the chute block; a 4.8-foot-high fin wall along the block center line and downstream from the chute block; and triangular-shaped extensions downstream from the blocks.

Each of these accessories either had no appreciable affect on the pressures or moved the low pressure region farther downstream from the block.

An air vent was also placed in the floor immediately downstream from the chute block. Preliminary tests at 75 and 83 percent gate opening indicated that the vent took no air. Different quantities of air were then forced through the vent. Small quantities of forced air lowered the minimum pressures and a comparatively large blast of air was required to dampen the pressure fluctuations and raise the minimum pressures.

These test results indicated that there were no known, practicable method of relieving or raising the low pressure in the basin floor immediately downstream from the block. It is possible, therefore, that cavitation erosion may occur in this region at gate openings above 50 percent.

Baffle Piers

Average pressures observed on the original baffle pier, Figure 15, indicated that cavitation would occur on the pier surface at reservoir elevation 4653 feet and gate openings above 50 percent, Table 3B. During the 1958 irrigation season, the Glendo Basin operated over a considerable period of time at gate openings of about 60 percent and reservoir elevations between approximately 4595 and 4625 feet, and no cavitation erosion on the prototype baffle piers was reported. Average pressures observed on the model indicated that the minimum pressures on the baffle piers will occur at 83 percent gate opening and reservoir elevation 4653 feet. Instantaneous pressures observed at 36 and 60 percent gate openings also showed that cavitation was probable at 60 percent gate opening. The fact that no cavitation erosion was noted on the prototype baffle piers was probably due to the lower-than-maximum operating heads and the large amount of entrained air in the jump.

As a result of the above studies, it was evident that additional stream lining of the baffle piers was required to insure cavitation-free piers at near-maximum gate openings and operating heads. Six baffle pier designs with varying degrees of stream lining were tested, Figure 16. Average pressures in or near the cavitation range were observed on Piers 1 (original), 2, and 3. Tests on these piers indicated that the lowest pressures occurred on the pier sides next to the training wall and the extension of the dividing wall; considerably higher pressures were observed on the sides next to the center line of the bay.

For structural reasons and ease of construction, it was desired that the shape of the existing pier be modified by placing a minimum of 6 inches of new reinforced concrete on the exposed pier surfaces, thus making the new pier 12 inches wider and longer and 6 inches higher than the original. Increasing the width and height of the piers had the effect of offering more resistance to the flow and permitted more stream lining of the pier without sacrificing its efficiency. Piers 3 through 6 were thus larger than Piers 1 and 2.

The minimum average pressure observed on Pier 4 was 23 feet below atmospheric at 75 percent gate opening and occurred on the elliptical curve near the upstream nose. Thus, still more stream lining was indicated in the vicinity of the pier nose.

Extreme stream lining of the sides was provided on Piers 5 and 6, Figure 16, and considerable improvement in the pressures was noted.

Pier	Minimum average pressure	Minimum instant pressure
1,2,3	-30 feet	Not obtained
4	-23 feet	Not obtained
5	-10 feet	-26 feet
6	0 feet	-15 feet

The above table clearly indicates the preference of Pier 6 over the other piers as far as pressures were concerned. Also, the basin performance, which is discussed later, was similar when either Pier 5 or 6 was installed. Therefore, Pier 6 (Figure 17) was chosen for installation in the prototype.

Average pressures observed on the recommended baffle pier are shown on Figure 18, and a tabulation of pressures for different gate openings and tail-water elevations is contained in Table 5. All observed average and instantaneous pressures were well above the cavitation range. A comparison of the variation of the instantaneous pressures on the original and recommended baffle pier for 60 and 83 percent gate openings is shown in Figures 19 and 20. Details of the recommended baffle pier is shown in Figure 21.

Basin Performance

The basin performance with the various test blocks and piers was evaluated primarily by recording the tail-water elevation when the hydraulic jump "swept" from the basin. "Jump sweepout" was defined as the tail-water elevation at which the entering flow broke through the tail water and was deflected upward at the baffle piers, Figure 22B.

Tail water and sweepout curves for the stilling basin are shown in Figure 23. The uppermost curve is the computed tail water curve used in originally designing the structure. Prototype tail-water elevations observed at Glendo during 1958 and 1959, however, showed that the existing tail water was considerably lower than the computed curve used in design.

In June 1959 test releases were made through the outlet works to determine, among other things, the stilling basin performance and the existing tail-water conditions in the outlet works. 4/ The test releases showed that the existing tail water, as observed in the powerhouse tailrace near the draft tubes, was from 0.5 to 1 foot lower than the design tail water when both the power units and the outlet works were operating, Figure 23. When releases were made through the outlets only (no flow through the powerplant), a still lower tail-water curve was obtained. The lower tail water for outlet flows only was attributed to the "ejector action" of the high-velocity flow at the downstream end of the stilling basin.

4/ Travel Report "Controlled Test Releases Through Glendo Dam Outlet Works and Powerplant--Glendo Dam," July 16, 1959, by W. E. Wagner.

Sweepout curves as determined from the model, are also shown in Figure 23. Curves A and B are the sweepout curves for the original and recommended stilling basins, respectively, with the reservoir elevation at 4653 feet. When the original basin was modified by lowering the block height and by additional stream lining of the baffle piers, the jump swept from the basin at a higher tail water elevation; thus some of the safety against sweepout, amounting to about 0.6 foot for a discharge of 10,000 second-feet, was lost by modifying the basin.

The sweepout characteristics for the stilling basin also were determined for reservoir elevation 4640, Curve C. In addition, the tail-water elevation at which the chute blocks were uncovered or the toe of the jump coincided with the downstream end of the chute block was determined for reservoir elevation 4640. These tail-water elevations are represented by Curve D.

Certain conclusions may be reached by comparing the position of Curves A, B, C, and D with the existing tail-water curves.

A. Reservoir surface at the top of the flood pool, or elevation 4653 feet:

1. The outlet works stilling basin will safely handle the design discharge of 10,000 second-feet when the powerplant is operating. Under full load both power units discharge 3,400 second-feet and provide about 1.4 feet of additional tail water which places the existing tail-water curve for powerplant and outlet works flows well above Curve B.

2. By placing one power unit in operation (discharge 1,700 second-feet), the tail water is raised a minimum of about 0.6 foot which places the existing tail-water curve for outlet flows only above sweepout Curve B at discharges less than 9,000 second-feet. Thus, a combined flow of 10,700 second-feet through one power unit and the outlet works can be released without the jump sweeping out. Additional safety against sweepout probably will exist, because the flow from one unit will partially nullify the "ejector action" and raise the tail-water curve above that for outlet flows only.

3. With no flow through the powerplant, the jump will sweep out when the outlet works discharge exceeds 8,000 second-feet.

B. Reservoir surface at elevation 4640 feet:

1. With no flow through the powerplant, the jump will sweep out when the outlet works discharge exceeds 9,200 second-feet.

2. With no flow through the powerplant, the chute blocks will become uncovered when the discharge reaches 8,000 second-feet. As the discharge increases above 8,000 second-feet, the toe of the jump moves downstream and at about 9,200 second-feet the

jump sweeps out. Discharges between 8,000 and 9,200 second-feet places the full jet impact on the baffle piers. Such a flow condition is not recommended for prolonged periods of operation.

Scour tests conducted with the original and recommended designs indicated that the basin modifications will not cause greater displacement of riprap in the outlet channel, Figure 22C and D. The scour patterns resulting from a discharge of 10,000 second-feet are practically identical for the two designs and are similar to that observed in the prototype when the basin was unwatered. It is concluded, therefore, that modifications to the chute blocks and baffle piers have not affected adversely the scouring characteristics of the flow in the outlet channel.

Training Wall Vibration

When Glendo outlet works was placed in operation during the summer of 1958, an audible thumping noise was noted in the stilling basin and vibrations were observed in the basin training walls, particularly the left wall which is cantilevered between the basin and the tailrace. There appeared to be a direct relationship between the pounding noise and the wall vibration, because the greatest wall deflection appeared to accompany the loudest thumps. The thumping noises and vibrations persisted through the 1958 irrigation season and became more pronounced during the latter part of the season when the outlet works discharge ranged between 4,000 and 5,500 second-feet. No power was generated during this period.

At the end of the 1958 irrigation season, the basin was unwatered and extensive cavitation damage to the sides of the chute blocks was found, Figure 2. The structure was modified during the winter of 1958-59 by changing the height and shape of the chute blocks and baffle piers as determined from the studies described in this report.

The powerplant was placed in operation in May 1959 and during the 1959 irrigation season the powerplant discharge varied between 2,000 and 3,600 second-feet and provided about 1 to 1-1/2 feet of additional tail water for the outlet works. The outlet works discharges during this period ranged between 3,000 and 5,000 second-feet, except for 6 days when the discharge averaged about 7,000 second-feet. No thumping noise or wall vibration were reported during these normal releases.

Thumping and vibration was noted, however, during the test releases in June 1959. The thumping was first observed when the outlet works discharge reached about 7,000 second-feet and persisted through the remainder of the tests, including 7,500 second-feet through the outlet works only and combined outlet and powerplant discharges of 7,500 up to 9,100 second-feet. Following these releases, which were made by increasing the discharge in increments of 500 second-feet, the outlet works test releases (no flow through the powerplant) were repeated with discharges decreasing from about 7,500 to 5,000 second-feet. Thumping noises and wall vibration were noted during each of these repeat tests. It is significant that vibration was not noted in the earlier tests until 7,000 second-feet was released while thumping noises and vibration were clearly noted at lower discharges of 6,000 and 5,000 second-feet during the repeat tests. Also, slightly higher tail-water elevations were recorded during the repeat test releases.

A possible explanation for the noises and vibration is the formation and collapse of cavitation envelopes on the flow surfaces in the vicinity of the chute blocks. Cavitation envelopes collapse audibly with tremendous force which could be transmitted to the walls, but the frequency is considerably higher than the frequency of the noises and vibration observed at Glendo. The fact that no cavitation damage was reported after the 1959 irrigation season fails to support this theory. However, the basin operated only a comparatively short period of time at discharges accompanied by noises and vibration.

Another explanation for the noises and vibration is the unsteady pressure forces on the blocks caused by variations of the separation and vortex flow patterns with and without cavitation. These variable loads on the blocks may be transmitted through the structure to the wall; or the pressure variations in eddy patterns near the trailing edge of the blocks might be transmitted to the wall and initiate the vibrations. Changes in tail-water elevations affect these separation and eddy patterns, which would explain why vibrations were observed during the repeat test releases and not during the earlier tests.

In an attempt to correlate the pressure variations with the vibration of the training walls at Glendo, piezometers were placed in the splitter wall extension between Bays 1 and 2 in the model, Figure 24, to determine the variation in pressure along the wall. Average and instantaneous pressures for three representative flow conditions were recorded, Table 1B. No attempt was made to represent the wall rigidity or to measure the wall vibration in the model.

The greatest pressure variation, equivalent to about 40 to 50 feet of water, occurred at Piezometer 1 located near the basin floor and about 3 feet downstream from the chute blocks. The pressure variation decreased to about 20 feet of water near the downstream end of the wall and to a few feet of water near the water surface. The magnitude of these pressure variations is sufficient to cause the wall to vibrate, particularly if the frequency of pressure variations coincides with the natural frequency of the training wall.

These tests are inconclusive in establishing the source of the thumping noises and vibration; they merely indicate that sufficient pressure variations to conceivably induce vibration are present along the training walls.

Table 1

PRESSURES ON FLARED WALLS AND SPLITTER WALL EXTENSION

A. PRESSURES ON FLARED WALLS

Gate opening	Tailwater elevation	Piezometric Pressure in Feet of Water — Piezometer	18	19	20	21	22	23	24	25	26	27	28	29
		1. Original Design (without air vents)												
100% [c] (12,800 cfs)	4504.7 (Normal)	Ave*	0.4	0.9	3.8	9.3	-29.8	-5.3	0.4	2.2	-34.0	-7.0	-6.7	-3.3
		Max**			26.3	28.2						-3.9		
		Min**			-13.9	0.7						-10.9		
75% [c] (9,500 cfs)	4503.5 (Normal)	Ave	-2.8	2.2	5.4	-10.7	-30.7	-3.7	-1.3	-0.6	-34.0	-6.8	-6.5	-5.3
60% [a] (4,500 cfs 2 gates)	4501.4 (Normal)	Ave	-17.8	7.2	5.2	9.8	-26.1	-23.5	-1.8	0.6	-34.0	-5.0	0.1	3.7
		Max			23.0	27.6						25.8		
		Min			-36.8	-23.0						-22.1		
50% [c] (6,400 cfs)	4502.4 (Normal)	Ave	-14.2	15.8	5.1	11.1	-12.3	1.3	2.8	2.6	-34+	-14.2	-13.1	-6.1
36% [a] (4,200 cfs)	4501.2 (Normal)	Ave	-16.6	18.0	7.8	12.0	2.9	4.2	4.2	3.7	-32.1	-1.5	4.0	7.9
		Max			59.3	36.9						49.8		
		Min			-45.5	-15.9						-81.1		
25% [c] (2,200 cfs) (2 gates)	4499.8 (Normal)	Ave	-3.5	17.5	6.9	11.5	0.7	0.9	1.3	1.7	-33.1	-12.2	-11.9	7.2
		2. With 2-1/2- by 10-inch Air Vent Installed												
100% [c]	4504.7 (Normal)	Ave	***	3.1	10.9	10.9	***	***	-3.5	-0.6	***	***	-0.2	0.7
		Max											5.3	
		Min											-7.0	
75% [c]	4503.5 (Normal)	Ave		1.5	7.6	8.4			-0.9	-0.7			-0.6	-0.2
60% [a]	4501.4 (Normal)	Ave		0.6	6.7	9.6			-2.2	0.7			-1.3	-1.5
		Max											-1.5	
		Min											-11.7	
50% [c]	4502.4 (Normal)	Ave		0.2	8.2	12.4			-1.7	1.8			-3.2	-2.9
36% [a]	4501.2 (Normal)	Ave		8.8	10.9	12.8			10.5	5.2			-3.4	-2.2
		Max											1.0	
		Min											-9.5	

B. PRESSURES ON SPLITTER WALL EXTENSION

		Piezometer	1W	2W	3W	4W	5W	6W	7W	8W	9W	10W	11W	12W	13W	14W	15W
83% [b] (10,000 cfs)	4505.2 (Normal plus 1-1/2 feet)	Ave	8.3	19.3	19.1	23.2	1.7	7.9	10.5	13.8	--	2.6	4.4	6.8	15.8	10.7	7.7
		Max	36.8	35.0	35.0	27.6	3.7	22.1	24.8	20.2		2.7	10.1	10.1	29.4	23.9	17.5
		Min	-18.4	4.6	1.8	20.2	0	0.9	0.9	12.0		0	1.8	6.4	2.7	1.8	0.9
	4506.7	Ave	14.7	21.2	22.1	24.9	3.1	9.4	13.2	15.6	--	4.8	6.6	8.3	18.4	13.6	9.9
		Max	42.3	33.1			3.7	18.4							31.3	24.8	18.4
		Min	-9.2	8.3			-4.0	0							5.5	1.8	2.7
60% [a] (4,500 cfs thru 2 gates)	4501.4 (Normal plus 1-1/2 feet)	Ave	8.3	14.2	18.6	20.2	0.4	7.4	9.6	11.0	--	0.6	3.7	4.0	12.1	8.5	5.9
		Max	26.7	23.9				11.0							20.2	16.6	12.0
		Min	-14.7	3.7				2.2							0.9	0	0
	4502.9	Ave	12.7	17.7	21.0	21.7	2.9	9.2	11.6	12.7	--	2.9	5.0	5.2	16.2	11.6	9.2
		Max	29.4	27.6			3.7	14.7							24.8	17.5	12.9
		Min	-1.8	11.0			1.8	5.5							9.2	7.4	5.5
36% [a] (4,200 cfs)	4501.2 (Normal)	Ave	16.4	19.3	20.2	20.4	5.9	9.8	11.0	11.2	0.4	2.8	3.3	3.3	18.8	14.2	11.0
		Max	26.7	23.9			6.4								23.9	16.6	13.8
		Min	7.4	17.5			2.7								17.5	11.0	7.4

Note: See Figures 4 and 24 for piezometer locations.
*Average piezometric pressure as measured by water manometer.
**Maximum and minimum piezometric pressure as measured by pressure cell.
***Piezometers were covered by air vent passages.
a Reservoir elevation = 4,625 feet.
b Reservoir elevation = 4,653 feet.
c Reservoir elevation = 4,669 feet.

Table 2

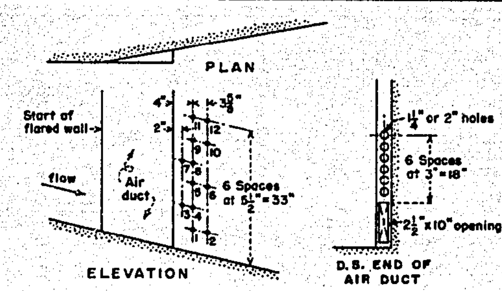
PRESSURES ON FLARED WALLS DOWNSTREAM FROM AIR VENTS
(reservoir elevation = 4,635 feet)

Piezometric pressure in feet of water

Gate opening	Tailwater elevation	Piezometer / Vents arrangement*	1 A	1 B	1 C	2 A	2 B	2 C	3 A	3 B	3 C	4 A	4 B	4 C	5 A	5 B	5 C	6 A	6 B	6 C
10% (1,220 cfs)	4500.3 (normal)	Ave	3.1	1.8	3.5	5.2	3.8	4.5	-0.7	-1.2	2.3	2.0	2.9	3.1	8.3	8.3	9.8	13.1	12.5	12.5
		Max	23.0	23.0	22.5				18.4	18.4	18.4	3.7	22.1	25.8	33.1	35.8	27.6			
		Min	-18.4	-23.0	-18.4				-36.8	-32.2	-20.2	-51.5	-36.8	-22.0	-27.6	-18.4	-18.4			
	4501.8	Max		23.9	23.9					18.4	18.4		22.1	33.1		29.4	35.0			
		Min		-22.1	-13.8					-27.6	-13.8		-36.8	-18.4		-18.4	-14.7			
15% (1,840 cfs)	4501.4 (normal)	Ave	0.7	-0.4	0.2	0	1.2	1.7	-2.9	-3.2	-1.0	-2.6	-1.5	-1.1	-3.1	4.8	7.4	11.3	11.6	11.6
		Max	27.6	23.0	27.6				18.4	18.4	18.4	3.7	18.4	27.6	44.1	34.9	40.5			
		Min	-23.0	-36.8	-20.2				-32.2	-36.8	-23.9	-62.5	-44.1	-25.7	-44.1	-33.1	-23.9			
	4502.9	Max		29.4	27.6					23.9	23.0		31.3	29.4		36.8	44.0			
		Min		-33.2	-20.2					-36.5	-22.1		-44.2	-23.9		-33.2	-23.9			
20% (2,430 cfs)	4501.8 (normal)	Ave	-0.4	-1.1	-1.3	-0.1	-0.1	0.9	-2.8	-2.9	-2.7	-3.3	-2.4	-2.8	-2.8	-0.9	-0.6	-2.5	2.0	2.9
		Max	27.6	14.7	27.6							9.2	14.7	18.4	45.0	27.6	38.6			
		Min	-23.0	-27.6	-22.5							-51.5	-27.6	-22.0	-55.2	-29.4	-25.7			
	4503.3	Max		27.6	29.4								27.6	22.1		42.3	47.8			
		Min		-36.8	-18.4								-36.8	-22.1		-36.8	-29.4			
25% (3,000 cfs)	4502.1 (normal)	Ave	-1.1	-1.5	-1.9	-1.2	-1.0	-1.2	-2.2	-2.3	-2.9	-2.0	-1.8	-2.8	-4.0	-2.9	-3.1	-3.4	-2.9	-3.7
		Max	14.7	14.7	18.4													36.8	-23.9	33.1
		Min	-23.0	-23.0	-27.6													-50.6	-36.8	-33.1
	4503.6	Max		16.0	23.0														36.8	36.8
		Min		-27.6	-23.0														-46.0	-33.1
30% (3,480 cfs)	4502.4 (normal)	Ave	-1.1	-1.7		-1.6	-1.6		-2.2	-1.6		-2.0	-2.0		-3.7	-3.5		-5.2	-4.8	
		Max	7.4	9.2	11.0													22.0	4.6	11.0
		Min	-14.7	-18.4	-14.7													-29.4	-32.2	-18.4
35% (4,020 cfs)	4502.7 (normal)	Ave	-1.5	-2.6		-2.5	-2.7		-2.6	-3.0		-2.0	-2.6		-3.3	-3.5		-4.9	-4.4	
		Max	9.2	5.6	9.2															
		Min	-13.8	-14.7	-18.4															
40% (4,580 cfs)	4503.0 (normal)	Ave	-2.4	-2.9		-3.2	-3.2		-3.3	-3.4		-2.8	-2.9		-3.7	-3.9		-4.5	-4.4	
		Max	4.6	5.6	3.7															
		Min	-22.5	-18.4	-11.0															
50% (5,700 cfs)	4503.5 (normal)	Ave		-2.9			-3.0			-3.2			-2.9			-3.9			-3.9	
		Max		4.6	3.7															
				-23.0	-23.0															
60% (6,750 cfs)	4504.0 (normal)	Ave		-1.5			-1.6			-1.9			-1.3			-2.0			-2.2	

Gate opening	Tailwater elevation	Piezometer / Vents arrangement*	7 A	7 B	7 C	8 A	8 B	8 C	9 A	9 B	9 C	10 A	10 B	10 C	11 A	11 B	11 C	12 A	12 B	12 C
10% (1,220 cfs)	4500.3 (normal)	Ave	7.2	7.2	8.6	9.8	10.3	12.1	10.1	9.6	9.8	9.9	9.7	9.9	9.8	9.4	9.4	9.2	8.8	8.8
		Max																		
		Min																		
	4501.8	Max																		
		Min																		
15% (1,840 cfs)	4501.4 (normal)	Ave	3.1	4.8	6.3	8.1	9.6	12.5	9.9	10.5	10.5	10.5	10.9	10.5	9.4	9.7	9.4	8.8	9.4	9.0
		Max																		
		Min																		
	4502.9	Max																		
		Min																		
20% (2,430 cfs)	4501.8 (normal)	Ave	-2.0	0.4	0.9	5.3	6.4	7.7	10.1	9.6	9.9	11.4	11.0	11.4	9.2	9.0	9.0	8.8	8.8	8.6
		Max	41.4	41.0	27.6															
		Min	-45.0	-46.0	-40.5															
	4503.3	Max		60.0	42.3															
		Min		-56.2	-40.5															
25% (3,000 cfs)	4502.1 (normal)	Ave	-6.8	-3.1	-2.9	-1.7	1.8	0.6	9.9	7.7	6.8	12.5	11.4	10.7	9.0	8.6	8.1	9.4	9.6	9.0
		Max	22.1	22.1	22.5	51.5	29.4	36.8												
		Min	-44.1	-36.8	-27.6	-49.7	-29.4	-36.8												
	4503.6	Max		27.6	27.6		40.5	38.6												
		Min		-35.0	-27.6		-36.8	-36.8												
30% (3,480 cfs)	4502.4 (normal)	Ave	-8.4	-4.0		-7.4	-3.1		7.5	3.7		14.0	9.6		10.7	7.9		10.7	10.1	
		Max	18.4	14.7	9.2	27.6	22.0	14.7												
		Min	-46.0	-18.4	-14.7	-44.2	-25.8	-20.2												
35% (4,020 cfs)	4502.7 (normal)	Ave	-7.4	-4.0		-9.9	-4.2		-0.9	-2.8		8.6	4.0		8.1	4.4		12.1	10.5	
		Max	29.4	5.5	4.6	18.4	11.0	5.5	55.0	27.6	23.9									
		Min	-14.7	-18.4	-14.7	-36.8	-22.0	-20.2	-55.0	-27.6	-22.0									
40% (4,580 cfs)	4503.0 (normal)	Ave	-5.9	-4.2		-6.4	-4.4		-8.6	-5.7		-0.6	-0.6		-0.4	0.7		9.9	8.8	
		Max	3.7	5.5	3.7	11.0	11.0	0	40.5	14.7	16.6									
		Min	-32.2	-22.1	-9.2	-36.8	-22.1	-16.6	-58.8	-27.6	-18.4									
50% (5,700 cfs)	4503.5 (normal)	Ave		-4.0			-4.0			-5.9			-4.6			-6.3			-1.1	
		Max								4.6	5.5		1.8	9.2		14.7	3.7			
										-32.2	-27.6		-33.1	-18.4		-33.1	-18.4			
60% (6,750 cfs)	4504.0 (normal)	Ave		-2.0			-1.7			-2.4			-2.4			-2.8			-2.9	

Note: See Figure 6 for location of air vents and piezometers.
*Vent arrangement A—One 2-1/2-inch by 10-inch slot.
B—One 2-1/2-inch by 10-inch slot and six 1-1/4-inch circular holes.
C—One 2-1/2-inch by 10-inch slot and six 2-inch circular holes.
**Average piezometric pressure as measured by water manometer.
***Maximum and minimum piezometric pressure as measured by pressure cell.



LOCATION OF PIEZOMETERS

Table 3

PRESSURE ON ORIGINAL CHUTE BLOCK AND BAFFLE PIER
(reservoir elevation = 4,653)

A. PRESSURES ON ORIGINAL CHUTE BLOCK

Gate opening	Tailwater elevation	Piezometric Pressure in Feet of Water													
		Piezometer	1	2	3	4	5	6	7	8	9	10	11	12	13
100% (12,200 cfs)	4504.4 (Normal)	Ave*	-29.0	-25.0	-13.8	-0.2	2.6	-35.0	-23.9	-7.7	-0.4	8.6	11.2	3.3	-10.1
83% (10,000 cfs)	4503.7 (Normal)	Ave	-29.1	-25.2	-10.7	0	2.4	-52.5	-29.4	-20.0	-4.2	5.7	8.3	-2.9	-5.7
75% (9,000 cfs)	4503.3 (Normal)	Ave	-25.4	-24.3	-5.1	0.9	2.4	-45.0	-25.7	-19.1	-2.9	6.4	8.6	-3.3	-7.0
60% a (4,500 cfs thru 2 gates)	4501.4 (Normal)	Ave Max** Min**	-17.1 18.4 -41.4	-10.7 23.0 -34.5	-2.9 25.3 -27.6	1.5 32.2 -18.4	2.6 27.6 -16.0	-35.0	-20.0	-9.7	0	6.4	7.4	-2.8 13.8 -12.0	-6.2 1.8 -12.4
50% (6,100 cfs)	4502.3 (Normal)	Ave	-13.8	-5.3	-0.4	3.1	3.5	-31.3	-9.9	-5.9	0.7	6.8	8.3	-0.5	-5.5
36% a (4,200 cfs)	4501.2 (Normal)	Ave Max Min	-0.2 16.1 -29.9	2.6 18.4 -24.0	5.9 15.6 -9.2	8.3 13.8 -2.8	10.1 11.9 -1.8	-14.5	0	3.9	8.3	11.9	15.1	12.7 11.9 2.3	2.6 4.6 -9.2
25% (3,100 cfs)	4500.6 (Normal)	Ave	2.4	4.6	7.7	9.6	11.2	-12.1	2.0	5.1	9.0	12.7	15.4	13.1	4.0

Note: See Figure 7 for piezometer locations.

B. PRESSURES ON ORIGINAL BAFFLE PIER

		Piezometer	30	31	32	33	34	35	36	37	38	39	40	41	42	46	47	48	49	50	51	52	53	54
100% (12,200 cfs)	4504.4 (Normal)	Ave	0.2	-7.7	-5.9	1.7	7.4	7.0	-35.0	-37.5	-6.6	9.6	11.8	0.7	8.1	-27.5	-37.5	-6.6	11.2	-11.2	5.3	1.3	-13.4	5.5
83% (10,000 cfs)	4503.7 (Normal)	Ave	2.0	-6.1	-3.1	1.1	7.2	7.0	-42.5	-31.1	-13.1	3.5	10.1	0.2	5.0	-32.5	-47.5	-20.8	10.3	-11.0	5.5	7.0	-17.6	4.0
75% (9,000 cfs)	4503.3 (Normal)	Ave	0	-8.1	-2.8	1.1	5.9	6.6	-35.0	-29.2	-3.9	6.2	10.1	1.7	6.4	-30.7	-40.0	-13.6	15.1	-4.8	7.2	12.3	-14.0	5.0
60% a (4,500 cfs thru 2 gates)	4501.4 (Normal)	Ave Max Min	4.0 20.2 -19.3	-3.9	3.1	5.3	8.3	9.7	-18.6 18.4 -50.6	-5.3 13.8 -20.7	2.2 29.9 -27.6	10.7 24.8 -3.2	13.6 46.0 14.7	7.0 14.7 0.9	11.6 17.9 9.6	-22.8	-8.5	1.3	23.9	11.2	13.2	25.4	10.1	14.7
50% (6,100 cfs)	4502.3 (Normal)	Ave	7.9	-2.9	5.1	7.2	9.2	11.0	-14.2	1.3	8.1	13.2	15.8	15.6	15.1	-15.4	2.0	7.9	6.8	13.2	14.7	25.4	13.1	15.6
36% a (4,200 cfs)	4501.2 (Normal)	Ave Max Min	10.7 4.6 3.2	6.6	9.0	11.4	12.3	12.5	2.0 11.0 -15.6	7.0 10.1 -9.2	13.8 10.1 3.7	16.7 10.5 7.3	17.3 10.5 8.4	11.0 4.1 1.8	15.4	4.6	8.3	14.5	16.2	12.1	15.4	14.7	13.1	17.1
25% (3,100 cfs)	4500.6 (Normal)	Ave	11.0	8.1	9.7	11.0	12.3	12.5	4.4	8.6	14.9	17.1	17.3	11.0	15.6	6.4	9.9	15.6	16.2	12.9	15.8	15.1	13.6	16.7

Note: See Figure 12 for piezometer locations.
*Average piezometric pressure as measured by water manometer.
**Maximum and minimum piezometric pressure as measured by pressure cell.
a Reservoir elevation = 4,625 feet.

Table 4

PRESSURES ON RECOMMENDED CHUTE BLOCK
(reservoir elevation = 4,653 feet)

Gate opening	Tailwater elevation	Piezometric Pressure in Feet of Water																									
		Piezometer	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
100% (12,200 cfs)	4504.4 (Normal)	Ave*	9.8	5.0	1.3	-0.6	-0.4	2.0	6.3	2.4	-0.7	0.2	1.1	9.6	8.1	4.2	2.7	2.2	1.8	3.7	6.1	10.8	-4.4	2.7	10.8	7.0	1.9
	4505.9	Ave*	12.8	9.2	6.4	4.8	4.2	6.1	8.8	5.9	3.7	5.3	6.4	11.4	10.3	7.2	6.3	5.9	5.7	7.8	10.3	13.5	-2.0	6.6	12.4	8.0	5.5
		Max**		17.5	9.2	15.1	12.4	19.0															17.3	23.2	15.6		29.4
		Min**		2.8	1.8	3.7	-7.9	-9.5															-4.4	-11.7	10.1		-36.8
	4507.4	Ave	15.5	11.6	9.0	7.8	7.6	9.0	12.3	9.9	8.0	9.4	10.3	14.9	14.0	11.2	10.3	9.9	9.7	11.6	13.6	16.9	1.8	10.1	16.2	10.8	9.0
83% 10,000 cfs	4503.7 (Normal)	Ave	8.6	2.4	-1.7	-3.9	-4.4	-3.1	4.2	0.6	-2.8	-1.7	-0.7	9.0	7.8	3.3	0.4	-1.1	-2.0	-0.2	0.9	5.5	-3.9	-1.5	8.6	7.4	-0.9
		Max	10.1	3.5	0.1	-3.1	-3.7	-2.2		1.4	-1.1	-1.9	0.2				0.2	-0.4	-1.3	1.0	1.7		-2.4	0.3	10.1	8.2	1.2
		Min	7.3	1.2	-2.0	-5.6	-5.8	-3.8		-1.0	-4.9	-4.0	-1.4				-2.6	-2.1	-2.8	-0.3	0.2		-4.1	-3.0	8.3	6.4	-1.6
	4505.2	Ave	11.4	6.3	3.3	2.0	1.8	3.1	5.2	1.8	-0.9	0.9	2.4	9.9	8.8	4.2	2.6	1.8	1.3	3.9	6.5	10.5	-4.6	-0.4	9.9	7.6	-0.6
		Max	17.5	31.3	19.3	27.8	32.6	28.1		4.4	6.6	9.0	8.1				7.3	8.7	8.5	8.9	10.1		0.7	16.9	14.9		15.8
		Min	6.4	-5.5	-2.8	-11.8	-7.9	-5.6		-1.8	-3.7	-3.2	-1.6				-0.5	-3.5	-2.5	0.2	0.9		-10.8	-0.7	8.9		-12.9
	4506.7	Ave	13.8	8.6	5.7	4.4	4.2	5.3	8.3	5.3	2.9	4.6	5.7	12.9	12.0	7.6	6.2	5.5	5.0	7.2	9.4	14.0	-1.5	5.5	12.9	9.0	4.7
		Max	44.0	39.2	32.4	28.7	35.3	34.6															10.1	19.5	37.7		25.8
		Min	-2.0	-9.2	-10.1	-15.4	-16.0	-16.0															-11.0	-7.1	0.9		-18.4
75% (9,000 cfs)	4503.3 (Normal)	Ave	8.8	2.4	-1.3	-3.3	-4.0	-2.9	4.0	0.6	-2.6	-1.3	-0.6	8.4	7.2	2.0	0	-1.3	-2.2	-0.4	0.9	5.1	-3.7	-2.4	8.1	7.2	-1.8
	4504.8	Ave	11.0	5.5	2.9	1.8	1.8	2.7	5.7	3.3	1.3	3.1	4.0	9.7	8.8	4.4	3.1	2.4	1.7	3.7	5.9	9.7	-4.6	-1.5	9.2	7.8	-1.3
		Max	22.1	13.8	25.8	17.7	23.4	23.6								12.9	14.2	12.9	9.0	[illegible]			4.6	12.2	16.5		27.6
		Min	5.5	0.9	-5.5	-8.1	-6.5	-6.3								0.9	-0.5	-1.9	-3.0	0.5			-12.0	-11.7	8.3		-12.9
	4506.3	Ave	13.6	8.1	5.5	4.6	4.8	5.9	8.6	6.2	4.2	5.7	6.4	12.8	12.1	8.0	6.6	6.1	5.3	7.8	9.6	14.7	-0.9	6.6	12.3	10.1	5.6
		Max	40.4	40.4	43.2	37.9	32.6	28.2															12.0	21.4	40.4		29.4
		Min	-4.6	-12.0	-19.3	-11.8	11.6	-9.5															-12.0	-6.2	-6.6		-14.7
75% (4,500 cfs thru 2 gates)	4501.4 (Normal)	Ave	7.9	3.3	1.5	1.1	1.5	2.0	3.7	1.8	0.2	1.8	2.6	7.6	7.0	3.3	2.2	1.5	0.6	2.4	4.0	7.9	-4.6	-2.4	6.1	6.1	-1.8
		Max							6.7	7.4	8.5	9.0	9.0										1.8	7.1	11.6		6.9
		Min							2.2	0.5	-2.1	-0.4	1.1										-10.1	-10.3	0.6		-12.0
	4502.9	Max							5.8	17.5	15.8	23.7	21.0										8.3	14.0	23.0		22.1
		Min							0.7	-4.6	-5.3	-3.9	-4.8										-10.1	-6.2	-0.9		12.9
50% (6,100 cfs)	4502.3 (Normal)	Ave	9.4	4.6	2.9	2.9	3.5	3.9	5.5	4.2	2.8	4.4	4.8	9.7	9.2	5.5	5.0	4.4	3.3	5.2	6.2	10.3	-1.8	1.8	7.6	8.1	2.1
		Max		17.4	25.0	24.1	19.1	19.5															8.6	12.4	27.0		23.0
		Min		-3.7	-7.3	-9.9	-5.9	-4.4															-10.1	-6.0	-1.6		-17.5
	4503.8	Ave	12.0	7.4	6.1	5.7	6.1	6.8	8.4	7.0	5.5	7.0	5.5	12.0	11.6	8.1	7.6	7.4	7.0	9.2	10.6	14.8	2.4	10.3	10.8	11.2	10.0
		Max		43.2	37.8	32.4	33.5	29.1															13.8	23.2	41.4		31.3
		Min		-15.6	-16.6	-11.8	-7.9	-13.2															-11.0	-4.4	-13.8		-18.4
	4505.3	Ave	14.0	10.1	8.6	8.4	8.8	9.7	10.4	9.0	7.6	9.2	9.7	14.4	14.2	10.4	9.9	9.7	9.4	11.6	13.4	17.3	5.7	14.2	13.4	14.7	13.8
		Max		41.4	34.0	30.6	30.8	25.4															13.8	23.2	41.4		31.3
		Min		-12.1	-13.8	-15.4	-11.6	-7.7															-4.6	-0.6	-7.4		-12.9
36%a (4,200 cfs)	4501.2 (Normal)	Ave	11.0	8.4	7.8	8.0	8.1	8.6	8.3	7.6	7.0	8.3	8.6	10.8	10.6	8.1	8.3	8.5	8.3	10.1	11.6	14.9	6.4	13.4	10.3	11.0	13.7
	4502.7	Max							37.5	23.9	25.0	26.5	24.6										13.8	26.0	41.4		29.4
		Min							-4.8	-9.2	-7.1	-3.9	-3.9										-0.9	4.8	0.9		0
25% (3,100 cfs)	4500.6 (Normal)	Ave	11.4	9.0	8.5	8.8	9.2	9.7	9.4	8.8	8.1	9.4	9.7	11.6	11.6	9.0	9.4	9.6	9.2	10.8	12.4	15.3	7.8	14.3	11.0	12.2	14.7
	4502.1	Ave	13.4	10.8	10.3	10.5	10.8	11.2	11.6	11.0	10.3	11.4	11.4	13.6	13.8	10.8	11.0	11.2	10.8	12.7	13.8	16.7	8.5	15.6	13.1	15.4	15.6

Note: See Figure 8 for location of piezometers.
*Average piezometric pressure as measured by water manometer.
**Maximum and minimum piezometric pressure as measured by pressure cells.
a Reservoir elevation=4,625 feet.

Table 5

PRESSURES ON RECOMMENDED BAFFLE PIER
(reservoir elevation = 4,653 feet)

Gate opening	Tailwater elevation	Piezometer number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
			Piezometric Pressure in Feet of Water																								
100% (12,200 cfs)	4504.4 (Normal)	Ave*	85.4	32.0	16.6	9.6	8.6	6.6	30.9	17.7	10.5	9.2	7.5	10.7	10.7	15.5	21.9	47.6	12.9	12.7	17.8	24.1	46.0	-2.6	-2.4	11.6	0.4
	4505.9	Ave*	74.9	31.6	17.5	13.1	13.1	12.0	30.4	17.1	12.3	12.0	11.0	15.3	15.8	19.7	24.3	42.2	16.2	16.7	21.0	25.0	41.4	-4.2	-3.7	14.9	3.1
		Max**	101.2	46.0	36.8	18.4	14.7	16.6	49.4	33.1	25.8	12.9				31.3	42.3	69.8	23.6	27.0	29.4	31.3	58.0	-2.9	1.7	16.9	12.0
		Min**	36.8	-1.8	2.7	-4.6	-1.8	3.7	17.7	-3.7	-1.8	-1.8				1.8	-1.8	23.8	10.7	7.5	14.7	3.7	24.8	-14.9	-13.0	13.1	0.9
	4507.4	Ave	66.4	28.2	19.1	16.4	16.6	15.6	25.8	18.2	15.8	15.5	14.9	18.8	20.2	24.7	29.3	43.1	19.3	20.6	24.3	28.7	42.3	3.1	-2.6	17.7	6.4
83% (10,000 cfs)	4503.7 (Normal)	Ave	133.2	32.0	7.9	11.7	2.8	-0.4	20.6	11.8	4.8	3.1	0.9	6.5	4.0	10.9	20.6	68.4	6.1	3.9	15.5	23.6	53.0	0	0	4.8	0.2
		Max			27.6	15.5	9.2	7.8			22.1	12.3	4.2	8.7	12.9	23.9								4.5	2.7	8.5	0.9
		Min			-1.8	-7.4	-3.7	0.4			0	-0.6	-4.1	4.2	0	3.7								-1.7	-3.7	1.1	-6.4
	4505.2	Ave	91.9	29.3	9.5	6.4	8.6	8.5	22.3	9.8	6.1	7.5	7.5	12.0	12.9	19.1	26.1	55.9	13.4	14.0	20.6	27.1	49.7	2.0	1.8	12.3	0.6
		Max			27.6	16.6	18.4	14.7			21.4	13.1	12.2	16.6	22.1	35.0			19.5	23.2				7.2	10.9	15.1	4.6
		Min			-5.5	-3.7	2.8	5.5			-5.3	0.2	4.4	9.2	5.5	9.2			8.5	3.0				-5.7	-5.7	9.5	-0.9
	4506.7	Ave	74.4	23.9	13.8	12.3	13.8	13.8	20.2	13.1	11.9	13.2	13.4	16.7	17.3	21.5	27.2	29.3	17.1	17.5	22.1	26.7	5.1	1.8	0.1	16.4	4.8
		Max			29.4	20.2	20.2	18.4			25.1	19.5	19.5	22.1	26.7	35.0			21.4	28.7				9.1	10.9	20.2	12.0
		Min			-5.5	0	5.5	7.4			1.1	6.0	10.3	12.9	8.3	7.4			12.2	8.5				-5.9	-7.5	12.9	2.8
75% (9,000 cfs)	4503.3 (Normal)	Ave	125.8	31.5	7.7	0.4	2.2	1.3	19.1	9.9	2.6	2.0	1.3	7.9	7.0	15.3	21.9	71.6	9.1	8.1	18.4	29.1	51.5	1.8	1.7	5.7	-0.2
		Max			20.2	9.2	9.2	3.7			9.5	7.6	6.7	12.0	16.6	25.8			15.9	19.5				7.2	6.3	10.1	6.4
		Min			0	-5.5	-1.8	-1.8			-2.5	-0.7	1.1	6.4	3.7	9.2			6.7	4.3				0.8	-0.1	4.6	-0.9
	4504.8	Ave	82.6	16.7	6.8	7.2	10.9	11.6	11.6	7.0	7.4	10.1	11.6	13.1	15.5	22.3	33.9	61.5	15.3	16.2	23.2	34.1	55.4	6.1	5.7	14.3	4.8
		Max			23.9	20.2	18.4	16.6			19.5	21.4	16.8	20.2	27.6	36.8								11.8	10.9	18.4	11.0
		Min			-12.9	-7.4	0.9	7.0			-4.4	3.0	6.7	7.3	5.5	3.7								1.7	1.7	9.2	3.7
	4506.3	Ave	67.9	20.6	13.2	13.1	15.3	15.8	17.3	13.2	13.2	14.5	15.3	18.0	18.2	22.8	28.9	48.2	17.9	18.0	23.0	26.5	46.0	5.3	4.8	17.9	6.1
		Max			27.6	22.1	21.3	20.2			20.5	17.7	19.5											12.7	13.6	22.1	15.6
		Min			-5.5	-3.7	6.4	11.0			-2.5	3.0	10.3											-1.1	-0.1	14.7	6.4
60% a (4,500 cfs thru 2 gates)	4501.4 (Normal)	Ave	46.4	7.9	7.2	10.3	13.8	15.5	5.1	7.2	9.9	13.1	14.7	17.3	17.5	23.0	32.0	48.6	16.7	17.5	23.4	30.4	45.1	8.3	7.7	17.1	7.5
		Max			22.1	22.1	20.2	18.4																10.9	10.9	21.0	13.8
		Min			-5.5	5.5	7.4	11.0																5.4	3.5	15.6	6.4
	4502.9	Ave	43.4	16.6	14.5	15.6	17.3	18.0	14.7	16.0	15.3	16.6	17.1	19.9	18.8	21.5	25.4	37.1	18.4	18.4	21.5	26.7	35.4	9.4	8.8	18.9	9.0
		Max			23.9	20.2	22.1	19.3																12.7	12.7	20.2	13.8
		Min			-3.7	7.4	9.2	12.9																4.5	4.5	15.5	8.3
	4504.4	Ave	39.6	22.3	19.5	19.0	19.3	19.1	21.4	18.8	18.0	18.4	18.4	23.2	21.0	22.3	24.1	28.5	20.2	20.4	22.1	24.1	30.4	9.9	9.6	20.1	10.5
50% (6,100 cfs)	4502.3 (Normal)	Ave	43.3	8.5	9.7	13.4	16.0	16.9	6.1	9.4	14.7	15.3	16.4	17.8	18.2	22.6	29.3	45.4	17.5	17.8	22.1	29.3	43.6	9.0	8.6	18.2	8.3
	4503.8	Ave	41.2	19.3	17.7	17.7	19.1	19.1	17.7	16.9	17.7	19.1	18.6	19.9	19.9	21.5	24.3	33.3	19.5	19.3	21.2	23.9	32.0	10.9	10.3	20.2	10.3
		Max			25.8	23.9	23.9	22.1																14.6	16.4	23.9	16.5
		Min			5.5	11.0	14.7	16.6																7.2	5.4	18.4	11.0
	4505.3	Ave	39.9	21.4	19.0	19.0	19.7	19.9	19.7	17.9	18.2	19.0	19.3	20.8	20.4	22.4	24.5	32.0	20.1	20.2	22.1	24.1	31.6	9.8	9.6	20.1	10.9
		Max																						12.7	10.0	22.9	16.5
		Min																						3.5	2.5	18.2	11.0
36% a (4,200 cfs)	4501.2 (Normal)	Ave	28.7	19.9	18.2	18.4	18.8	18.8	18.4	17.5	17.7	18.0	18.4	19.5	19.3	19.5	20.8	24.7	19.0	18.6	19.3	20.2	23.9	11.2	10.9	19.5	10.9
	4502.7	Ave	33.5	21.9	20.1	20.1	20.2	20.1	20.2	18.8	18.8	19.1	19.3	20.8	20.6	21.4	22.8	27.6	20.2	19.9	20.8	22.1	26.7	12.5	12.3	21.2	12.0
		Max			25.8	25.8	22.1	20.2																14.6	14.6	22.1	16.5
		Min			14.7	17.3	16.6	16.6																5.4	9.1	18.4	12.9
	4504.2	Ave	35.2	22.5	20.4	20.2	20.2	20.6	21.7	19.9	19.9	20.1	20.2	21.9	22.1	23.0	24.8	29.3	21.4	21.7	23.0	24.1	28.7	12.0	11.6	21.4	12.3
25% (3,100 cfs)	4500.6 (Normal)	Ave	28.7	19.7	18.2	18.2	18.6	18.4	18.6	17.5	17.5	17.7	17.9	19.1	19.0	19.3	20.1	23.9	18.4	18.2	19.0	19.5	23.8	11.2	10.9	18.8	10.7
		Max																						12.7	12.7	19.3	15.6
		Min																						10.0	10.0	16.6	12.0
	4502.1	Ave	30.2	21.0	19.5	19.3	19.7	19.5	19.9	18.8	18.8	19.1	19.5	20.4	20.4	20.8	22.1	26.1	19.9	19.7	20.2	21.5	25.4	12.1	12.0	20.1	11.8
	4503.6	Ave	31.7	23.0	21.4	21.4	21.9	21.9	22.1	20.6	20.4	20.8	20.6	22.1	22.1	22.8	23.7	27.4	21.4	21.4	22.3	23.2	26.7	13.2	13.1	21.5	13.1

Note: See Figure 14 for location of piezometers.
*Average piezometric pressure as measured by water manometer.
**Maximum and minimum piezometric pressure as measured by pressure cell.
a Reservoir elevation = 4,625 feet.

Table 6

PRESSURES ON STILLING BASIN FLOOR
(reservoir elevation = 4,653 feet)

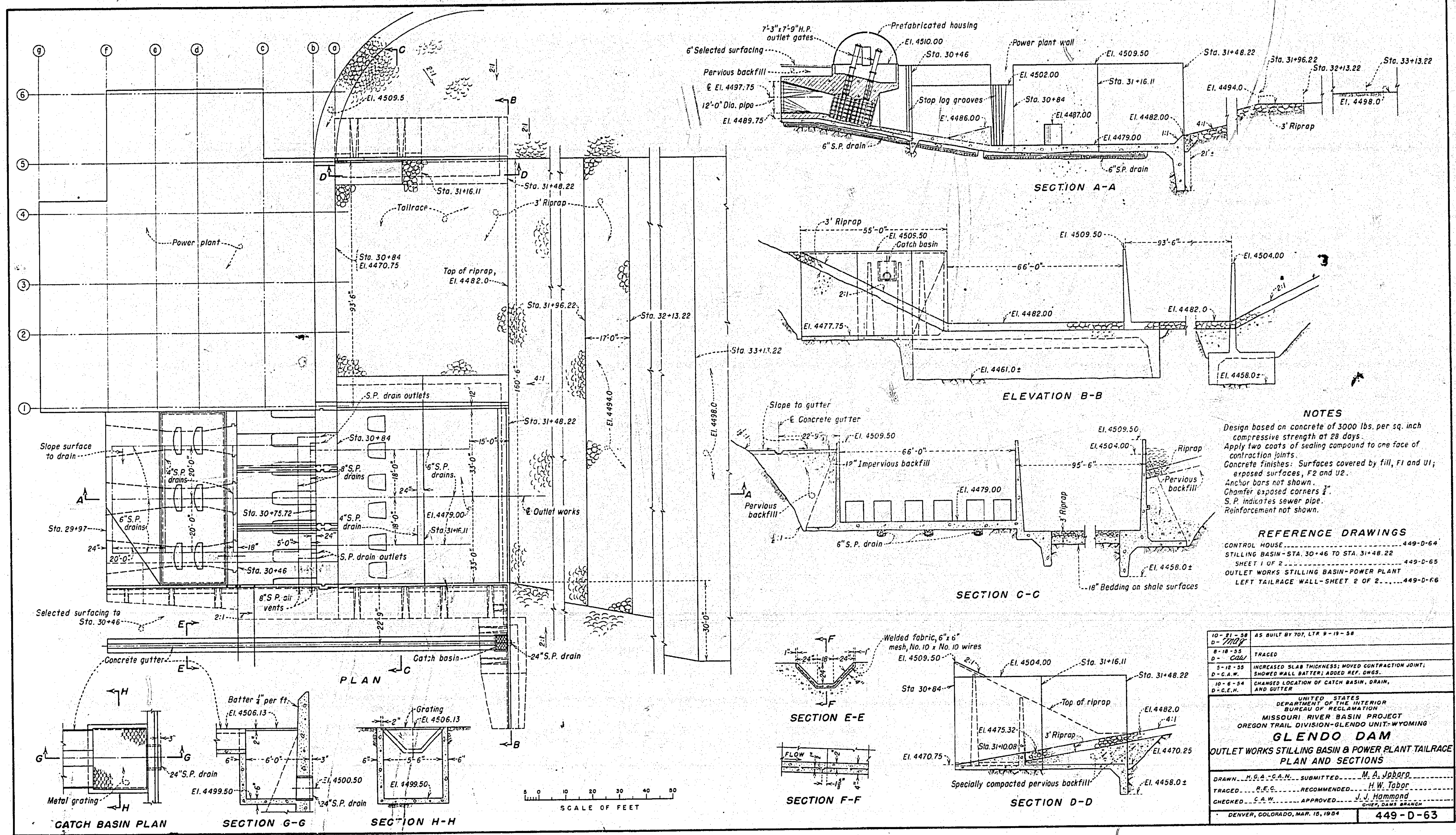
A. FLOOR PRESSURES DOWNSTREAM FROM ORIGINAL CHUTE BLOCK

Gate opening	Tailwater elevation	Piezometric Pressure in Feet of Water												
		Piezometer	1	2	3	4	5	6	7	8	9	10	11	12
100% (12,200 cfs)	4504.4 (Normal)	Max**	23.0	50.0	--	24.8	73.6	--	--	69.0	--	49.7	55.2	55.2
		Min**	-18.4	-36.8	--	-23.9	4.6	--	--	4.6	--	1.8	-9.2	-55.2
60% [a] (4,500 cfs thru 2 gates)	4501.4 (Normal)	Max	7.4	27.6	--	11.0	32.2	--	--	41.2	--	6.4	7.4	31.3
		Min	-11.0	-8.3	--	-12.9	-16.6	--	--	-27.6	--	-16.6	-17.5	-33.1
	4502.9	Max	19.3	36.8	--	25.8	36.8	--	--	44.2	--	12.9	35.0	44.2
		Min	-18.4	-25.8	--	-27.6	-27.6	--	--	-22.1	--	-20.2	-49.7	-36.8
50% (6,100 cfs)	4502.3 (Normal)	Max	14.7	27.6	--	12.0	31.3	--	--	41.2	--	9.2	20.2	38.6
		Min	-15.6	-14.7	--	-16.6	-35.0	--	--	-31.3	--	-14.7	-33.1	-33.1

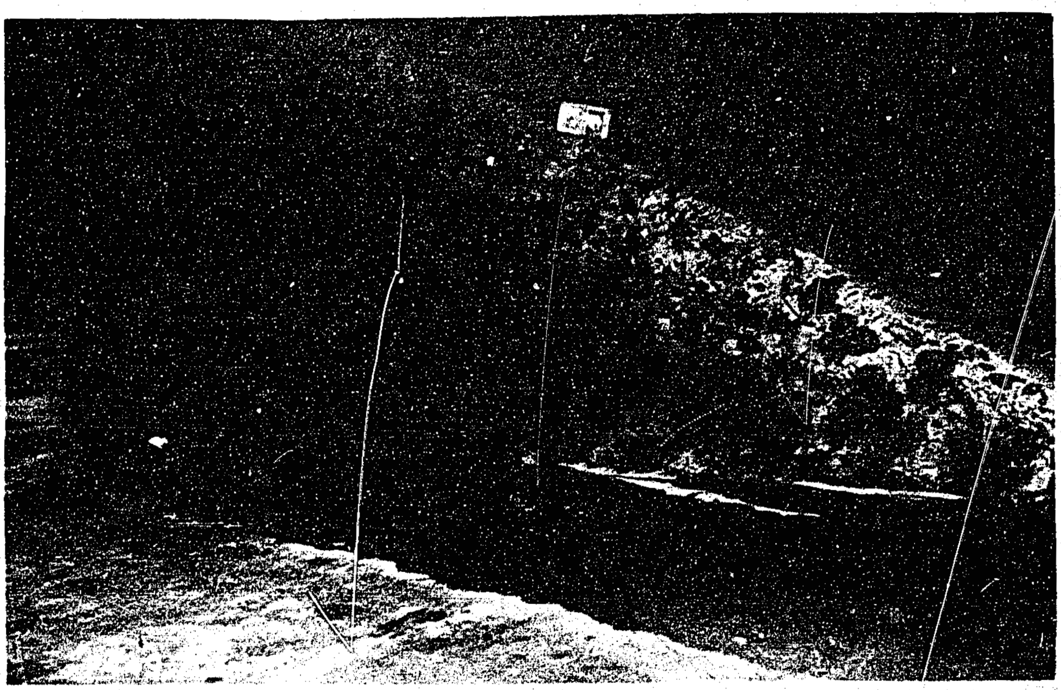
B. FLOOR PRESSURES DOWNSTREAM FROM RECOMMENDED CHUTE BLOCK

Gate opening	Tailwater elevation	Piezometer	1	2	3	4	5	6	7	8	9	10	11	12
100% (12,200 cfs)	4504.4 (Normal)	Ave*	-0.9	1.8	11.4	-1.3	-0.7	10.7	11.0	1.5	19.1	-3.7	-5.5	-5.7
		Max	22.1	26.7		19.3	30.3			53.4		14.7	25.8	41.4
		Min	-18.4	-35.0		-18.4	-42.4			-42.3		-17.5	-50.6	-55.2
	4505.9	Ave	4.6	7.2	19.1	3.3	4.2	18.0	19.9	13.6	24.8	0.4	-3.9	3.7
		Max	40.5	69.5		27.6	59.8					26.7	41.4	73.6
		Min	-22.1	-36.8		-41.4	-32.2					-23.9	-64.4	-46.0
	4507.4	Ave	8.1	10.5	21.3	7.0	8.5	20.8	23.2	16.9	27.2	3.7	-1.1	8.1
		Max										31.3	46.0	59.8
		Min										-23.9	-36.8	-50.6
83% (10,000 cfs)	4503.7 (Normal)	Ave	-1.1	7.4	10.7	-0.9	4.4	10.1	2.2	-1.1	0.7	-1.1	-0.6	0.5
		Max	-0.6	6.4	11.0	-0.9	5.8	11.5	3.0	-1.1	2.3	-1.4	-0.6	0.7
		Min	-2.5	1.8	3.2	-3.2	0.9	3.5	0	-3.2	-3.0	-4.1	-3.7	-1.7
	4505.2	Ave	-1.5	6.2	13.4	-1.8	3.3	12.7	9.7	1.5	16.2	-2.2	-2.8	0
		Max	23.9	32.2	59.8	21.1	41.4	59.8	64.4	55.2	73.6	24.8	14.7	55.2
		Min	-30.3	-27.6	-23.0	-21.1	-33.1	-18.4	-36.8	-32.2	-27.6	-20.2	-22.1	-27.6
	4506.7	Ave	4.6	8.6	17.1	4.4	7.4	16.9	18.0	12.3	22.8	1.8	0.5	5.5
		Max	27.6	50.6	55.2	25.8	46.0	55.2	64.4	55.2	64.4	28.5	35.8	41.4
		Min	-18.4	-32.2	-18.4	-25.8	41.4	-18.4	-23.0	-23.0	-13.8	-30.3	-46.8	-36.8
75% (9,000 cfs)	4503.3 (Normal)	Ave	-0.7	6.4	9.2	-1.1	5.9	9.0	1.3	-1.1	0.9	-0.9	-0.9	0.2
		Max	-0.4	10.6		-0.9	8.3		3.7	-0.4	2.3	-0.7	-1.1	1.2
		Min	-5.1	1.4		-5.5	0.4		-1.2	-5.8	-1.6	-4.1	-4.6	-2.3
	4504.8	Ave	-1.3	5.1	10.5	-1.8	3.3	10.3	7.7	0.2	13.2	-2.8	-3.5	-0.9
		Max	19.3	23.0		16.6	31.3			46.0		11.0	7.4	41.4
		Min	-20.2	-23.0		-22.1	-28.5			-30.3		-22.0	-23.9	-32.2
	4506.3	Ave	4.6	9.4	16.9	4.2	6.4	17.3	18.0	11.8	22.2	2.8	0.5	5.5
		Max	29.4	46.0								19.3	23.0	55.2
		Min	-29.4	-38.0								-16.6	-46.0	-36.8
50% (6,100 cfs)	4502.3 (Normal)	Ave	1.3	5.9	10.1	0.7	5.2	10.7	9.4	4.6	14.9	0	-0.7	2.0
		Max	13.8	44.2		20.2	27.6			36.8		12.9	23.9	31.4
		Min	-11.0	-33.1		-16.6	-20.2			-9.2		-12.9	-24.8	-23.0
	4503.8	Ave	8.5	11.8	18.0	7.7	10.3	18.8	18.8	16.0	20.6	7.9	5.5	11.6
		Max										31.3	33.1	50.6
		Min										-12.9	-32.2	-27.6
	4505.3	Ave	14.2	16.0	21.5	13.2	15.1	21.4	21.5	20.1	23.6	13.0	10.3	13.6
		Max										29.4	36.8	41.4
		Min										-4.6	-24.8	-23.0

Note: See Figure 19 for location of piezometers.
*Average piezometric pressure as measured by water manometer.
**Maximum and minimum piezometric pressure as measured by pressure cell.
a Reservoir elevation = 4,625 feet.


PLAN
SECTION A-A
ELEVATION B-B
SECTION C-C
SECTION D-D
SECTION E-E
SECTION F-F
CATCH BASIN PLAN
SECTION G-G
SECTION H-H
SCALE OF FEET
Power plant
Tailrace
Power plant wall
Prefabricated housing
7'-3" x 7'-9" H.P. outlet gates
6" Selected surfacing
Pervious backfill
12'-0" Dia. pipe
Stop log grooves
3' Riprap
Catch basin
Concrete gutter
S.P. drain outlets
Outlet works
Selected surfacing to Sta. 30+46
Metal grating
NOTES
Design based on concrete of 3000 lbs. per sq. inch compressive strength at 28 days.
Apply two coats of sealing compound to one face of contraction joints.
Concrete finishes: Surfaces covered by fill, F1 and U1; exposed surfaces, F2 and U2.
Anchor bars not shown.
Chamfer exposed corners 3/4".
S.P. indicates sewer pipe.
Reinforcement not shown.
REFERENCE DRAWINGS
CONTROL HOUSE.......449-D-64
STILLING BASIN-STA. 30+46 TO STA. 31+48.22 SHEET 1 OF 2.......449-D-65
OUTLET WORKS STILLING BASIN-POWER PLANT LEFT TAILRACE WALL-SHEET 2 OF 2.......449-D-66
AS BUILT BY 707, LTR 9-19-58
TRACED
INCREASED SLAB THICKNESS; MOVED CONTRACTION JOINT; SHOWED WALL BATTER; ADDED REF. DWGS.
CHANGED LOCATION OF CATCH BASIN, DRAIN, AND GUTTER
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI RIVER BASIN PROJECT
OREGON TRAIL DIVISION-GLENDO UNIT-WYOMING
GLENDO DAM
OUTLET WORKS STILLING BASIN & POWER PLANT TAILRACE
PLAN AND SECTIONS
DRAWN H.G.A.-C.A.N. SUBMITTED M. A. Jabara
TRACED R.E.C. RECOMMENDED H.W. Tabor
CHECKED C.A.W. APPROVED J. J. Hammond
CHIEF, DAMS BRANCH
DENVER, COLORADO, MAR. 15, 1954
449-D-63

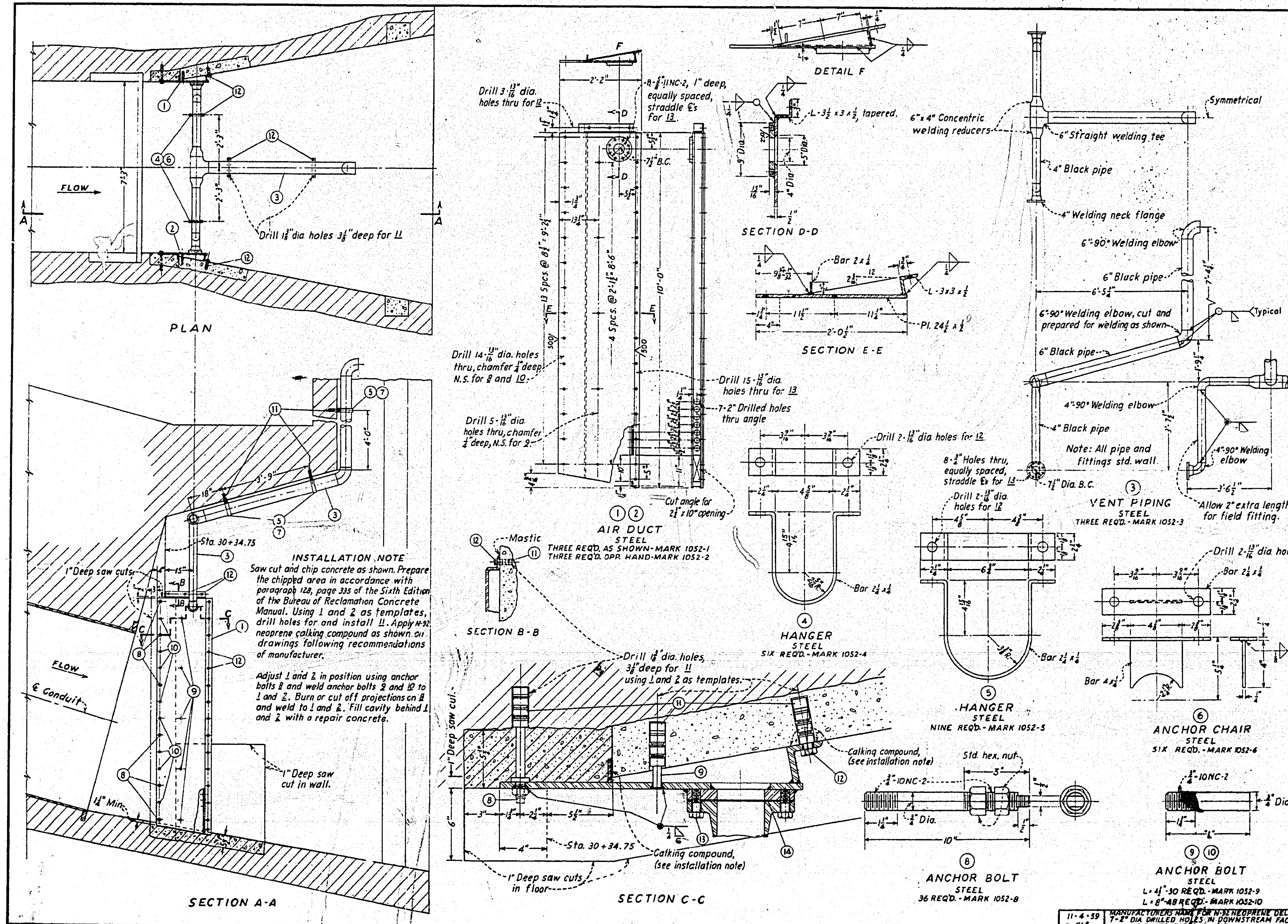
A. Right flared wall of Outlet Bay 3. Maximum depth of erosion is 3 inches at flared wall and 8 inches in floor at stop-log slot.



B. Left side of center chute block in Outlet Bay 2. Maximum depth of erosion is 17 inches.

GLENDO DAM OUTLET WORKS

Cavitation erosion on flow surfaces after 1958 irrigation season.



LIST OF PARTS - AIR ADMISSION EQUIPMENT FOR THREE OUTLETS

PART NO.	NO. REQ'D	DESCRIPTION	MATERIAL
1	3	Air duct	Steel
2	3	Air duct	Steel
3	3	Vent piping	Steel
4	6	Hanger	Steel
5	9	Hanger	Steel
6	6	Anchor chair	Steel
7	9	Anchor chair	Steel
8	36	Anchor bolt	Steel
9	30	Anchor bolt	Steel
10	48	Anchor bolt	Steel

UNDETAILED PARTS

PART NO.	NO. REQ'D	DESCRIPTION	USED WITH PARTS	MATERIAL
11	252	¾"-3 Unit threaded expansion anchor	8, 9, 10 & 12	lead-steel
12	138	¾"-10NC-2 x 3" Hex. hd. bolt	1, 2, 4, 5, 6, 7 & 11	Steel
13	48	⅝"-11NC-2 x 1¾" Hex. hd. bolt	1, 2 & 3	Steel
14	6	Gasket-6⅞" O.D. x 4" I.D. x ⅛" thick	1, 2 & 3	Cranite or equal

Contractor to furnish suitable high-class commercial materials.

Total estimated weight .... 5600 pounds

11-4-59 D.	MANUFACTURERS NAME FOR N-92 NEOPRENE DELETED. 7-2" DIA DRILLED HOLES IN DOWNSTREAM FACE OF AIR DUCTS, PARTS 1 AND 2.
12-5-58 D.	GENERAL REVISION FOR CONTRACTOR FURNISH AND INSTALL
11-26-58 D.	SEC. C-C, GROUT POCKET WAS 3" DEEP. PART 8 WAS 7½" LONG. PART 10 WAS 5½" LONG

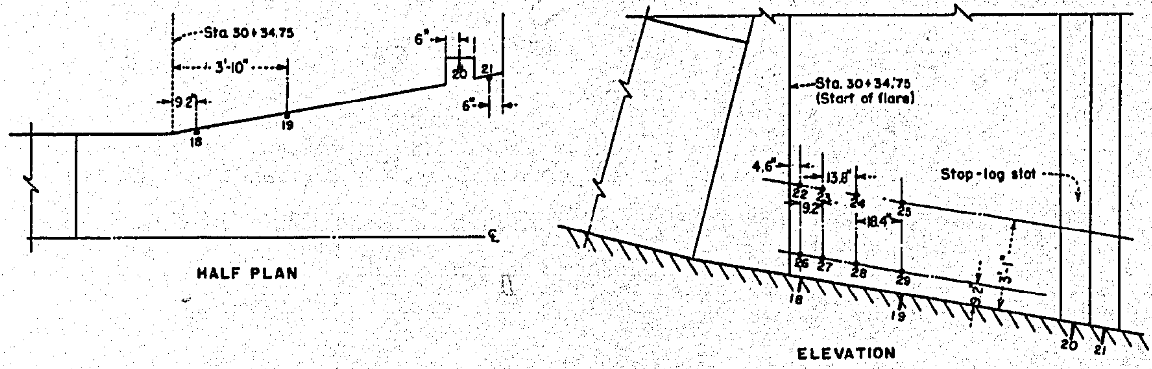
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI RIVER BASIN PROJECT
OREGON TRAIL DIVISION-GLENDO UNIT-WYOMING

GLENDO DAM
OUTLET WORKS
AIR ADMISSION EQUIPMENT
INSTALLATION - DETAILS - LIST OF PARTS

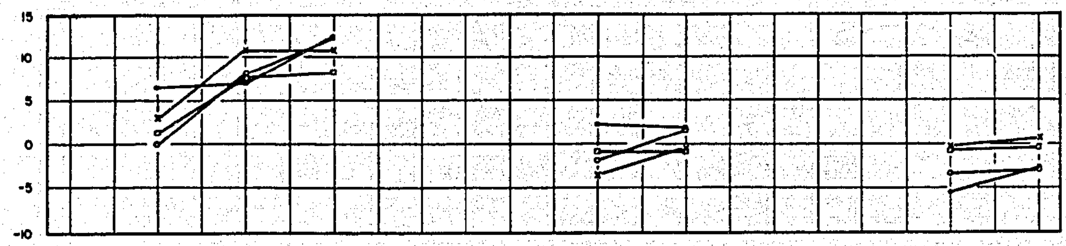
DRAWN: G.C.H. SUBMITTED: J.C. Gilbert
TRACED: RECOMMENDED:
CHECKED: M.L. APPROVED: H.E. Shade, CHIEF, MECHANICAL BRANCH

DENVER, COLORADO, OCT. 1958 — 449-D-1052

FIGURE 4
REPORT HYD.-461

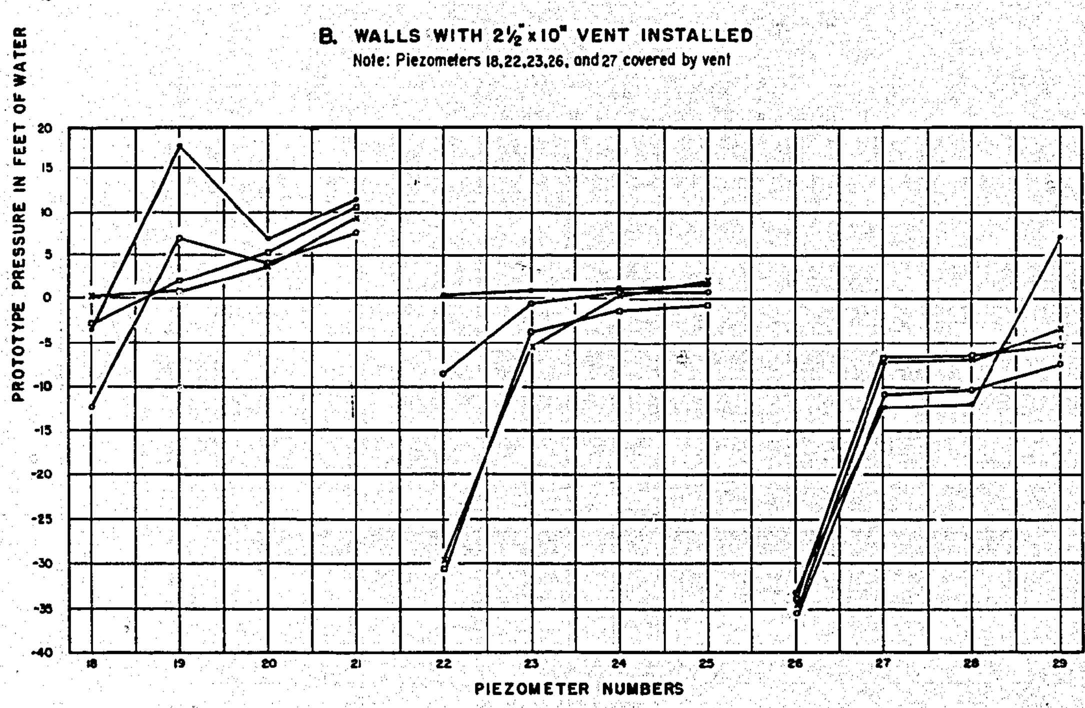


A. LOCATION OF PIEZOMETERS



B. WALLS WITH 2½" x 10" VENT INSTALLED

Note: Piezometers 18, 22, 23, 26, and 27 covered by vent



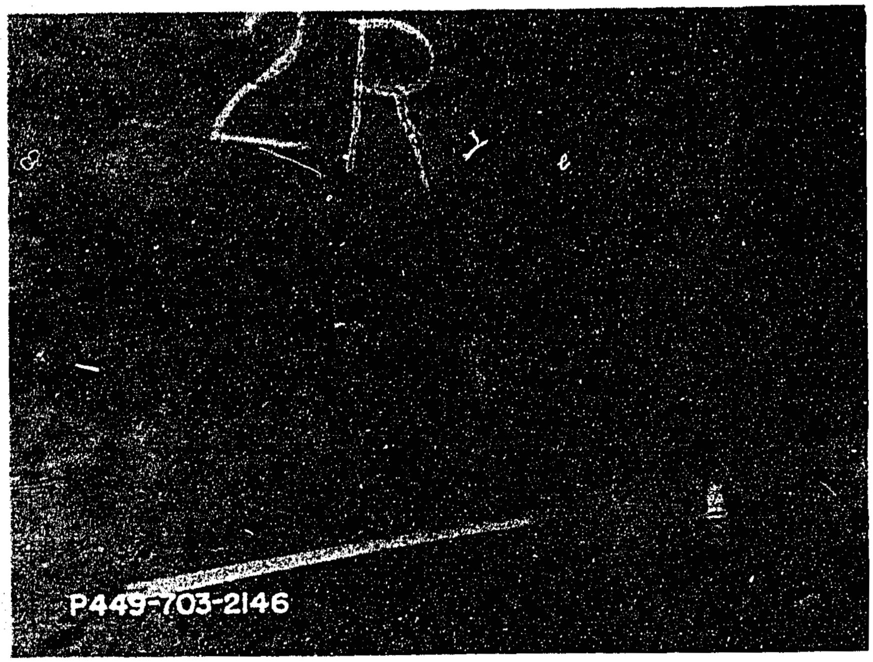
C. WALLS AS CONSTRUCTED (NO VENTS)

x———x = 100% Gate Opening
o———o = 75% Gate Opening
•———o = 50% Gate Opening
•———• = 25% Gate Opening

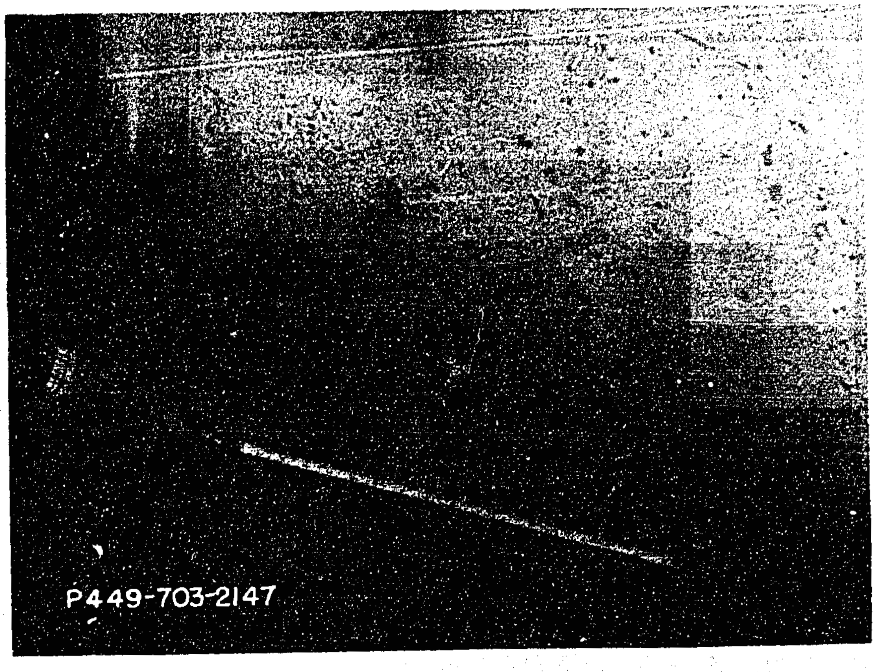
GLENDO DAM OUTLET WORKS

AVERAGE PRESSURES AT FLARED WALLS

1:18.4 SCALE MODEL



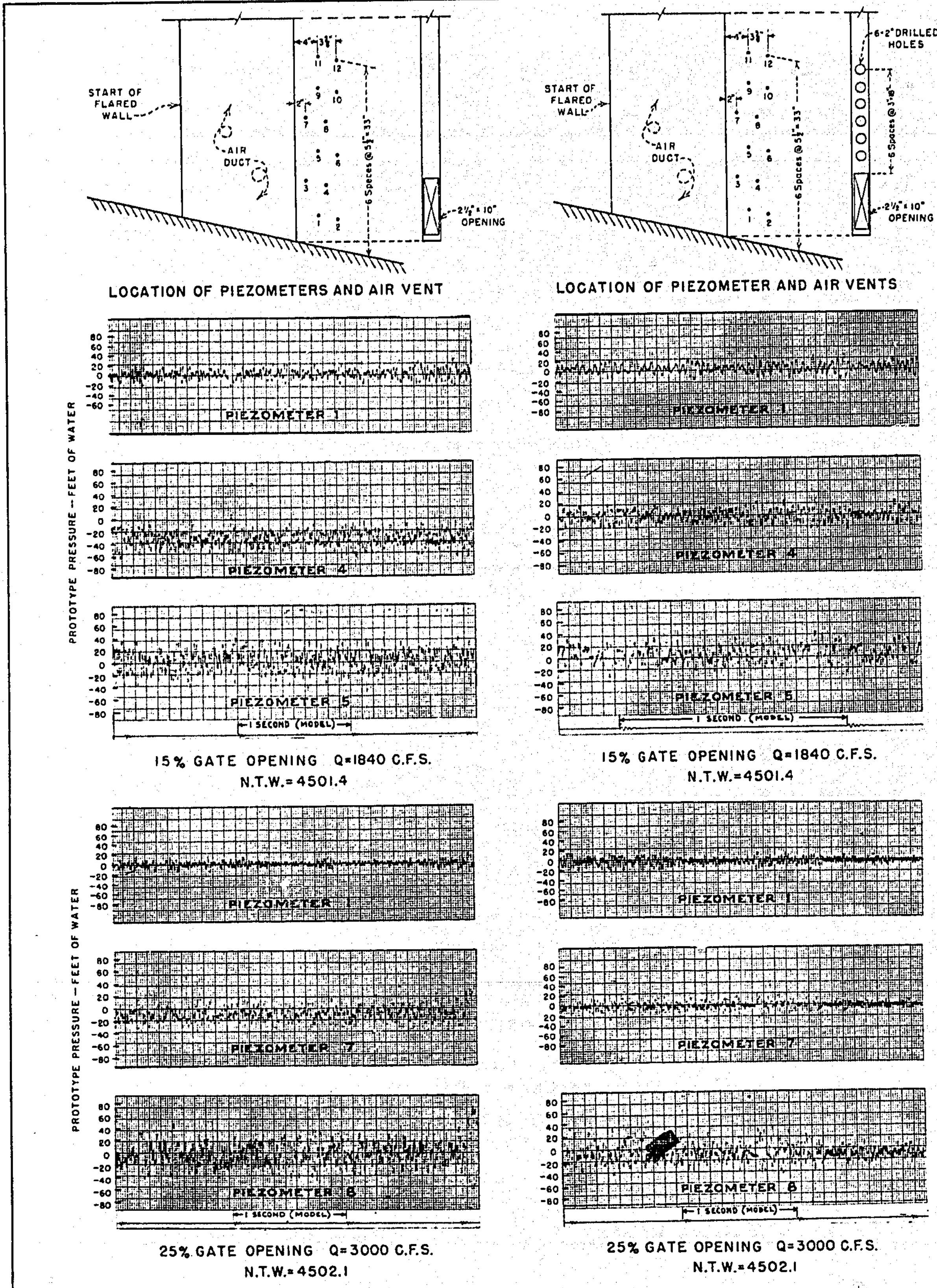
A. Right flared wall of Outlet 2.



B. Left flared wall of Outlet 3.

GLENDO DAM OUTLET WORKS

Cavitation-Erosion along flared walls after
1959 irrigation season.



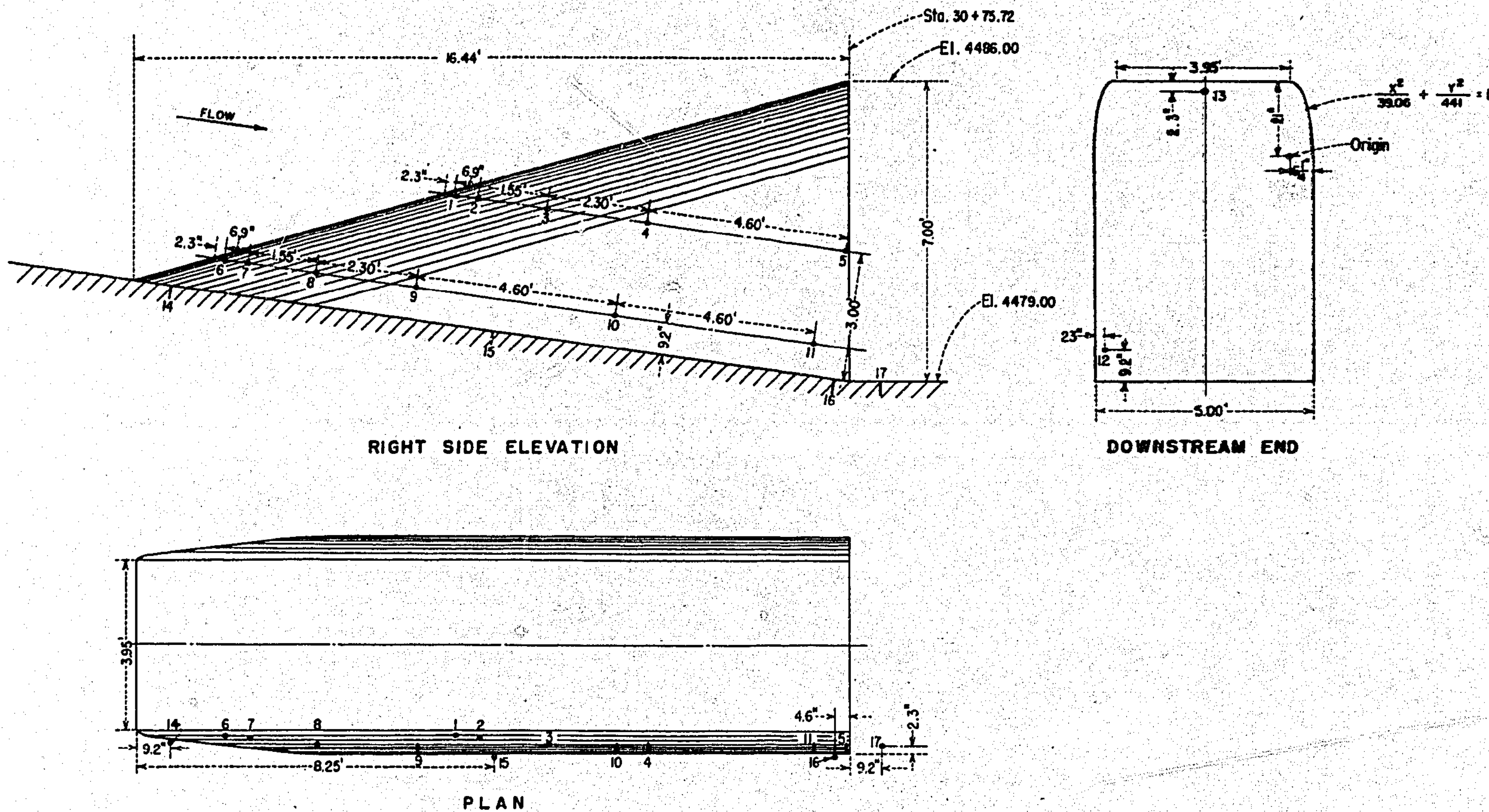
A. WITH 2½" x 10" VENT

B. WITH 2½" x 10" VENT AND 6-2" VENTS

GLENDO DAM OUTLET WORKS

AIR VENT STUDIES

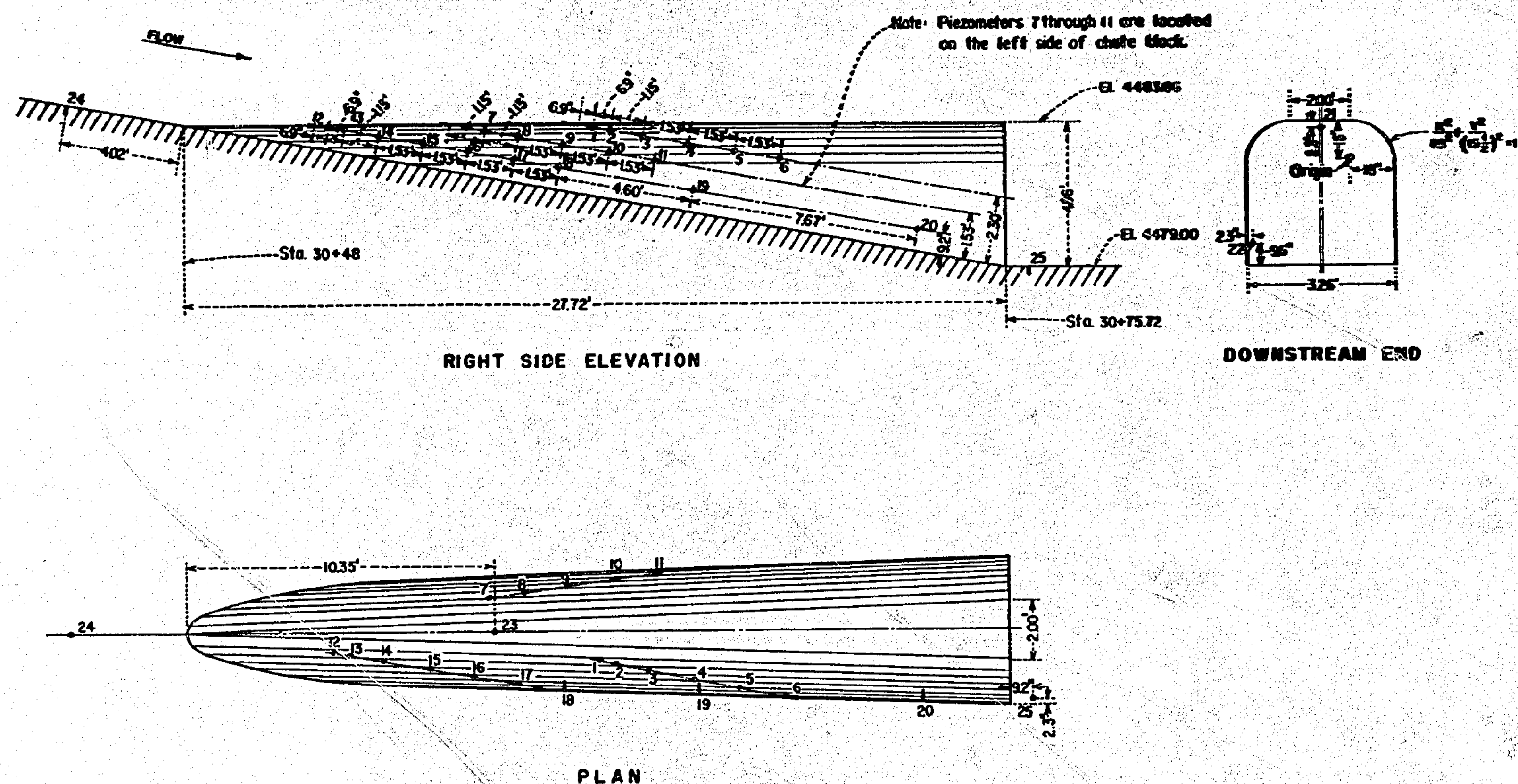
SCALE MODEL 1:18.4



GLENDO DAM OUTLET WORKS

PIEZOMETER LOCATIONS IN ORIGINAL CHUTE BLOCK

1:18.4 SCALE MODEL



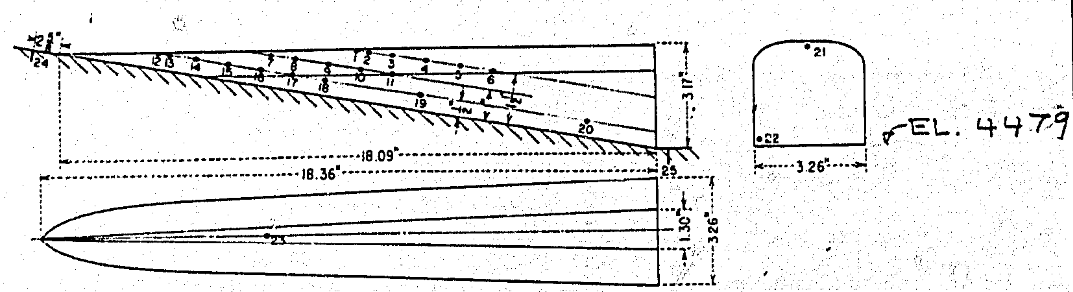
GLENDO DAM OUTLET WORKS

PIEZOMETER LOCATIONS IN RECOMMENDED CHUTE BLOCK

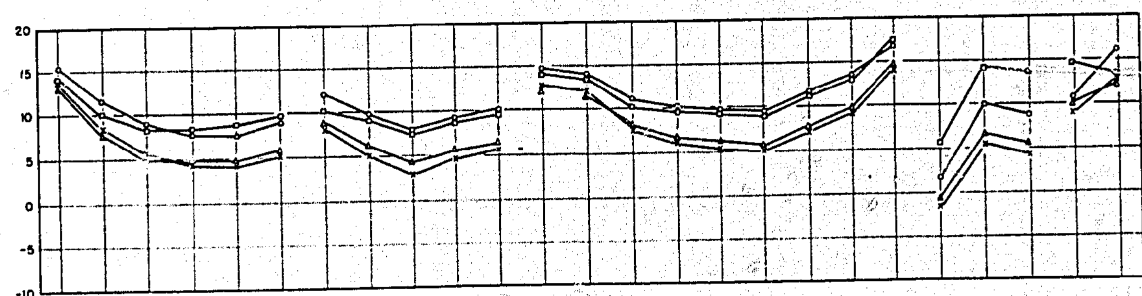
1:18.4 SCALE MODEL

FIGURE 8
REPORT HYD.-461

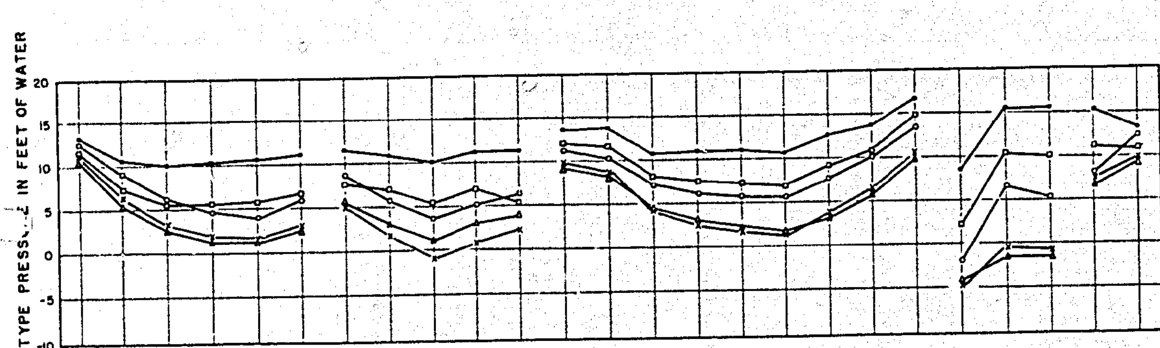
FIGURE 9
REPORT HYD-461



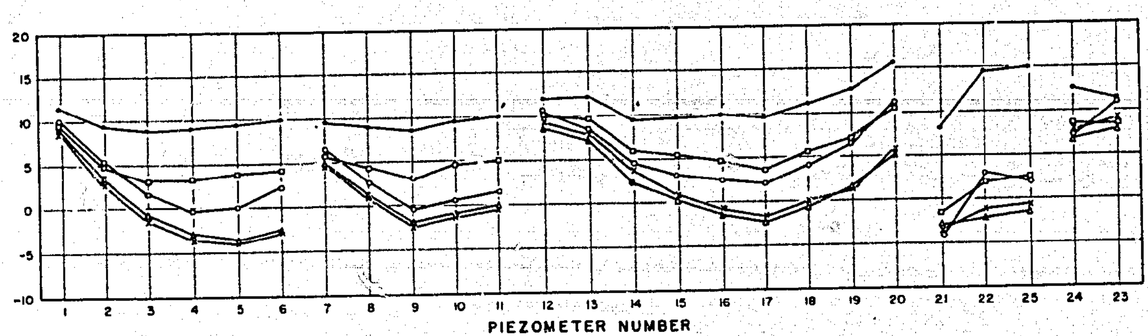
A. PIEZOMETER LOCATIONS FOR CHUTE BLOCK NO. 5



B. NORMAL TAILWATER PLUS 3 FEET



C. NORMAL TAILWATER PLUS 1½ FEET



D. NORMAL TAILWATER

= 100% Gate Opening
= 83% Gate Opening
= 75% Gate Opening
= 50% Gate Opening
= 25% Gate Opening

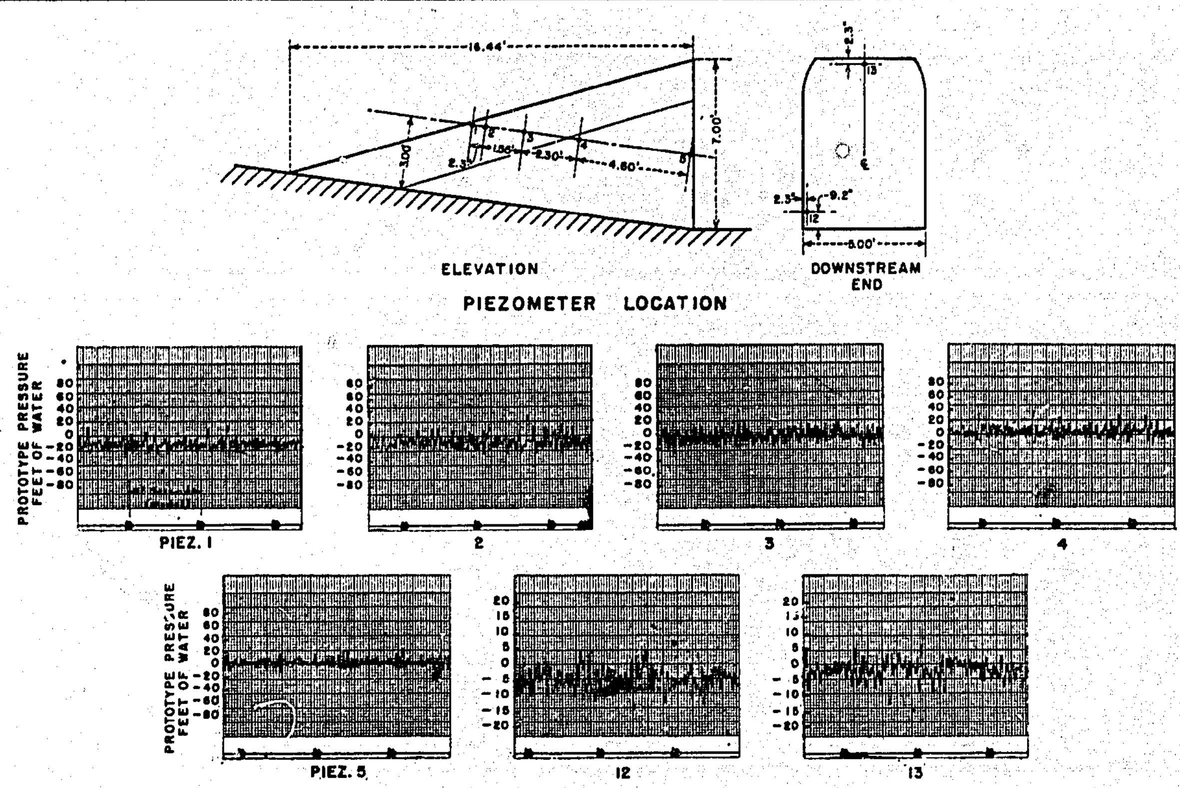
GLENDO DAM OUTLET WORKS

AVERAGE PIEZOMETRIC PRESSURES ON CHUTE BLOCK NO. 5 (RECOMMENDED)

1:18.4 SCALE MODEL

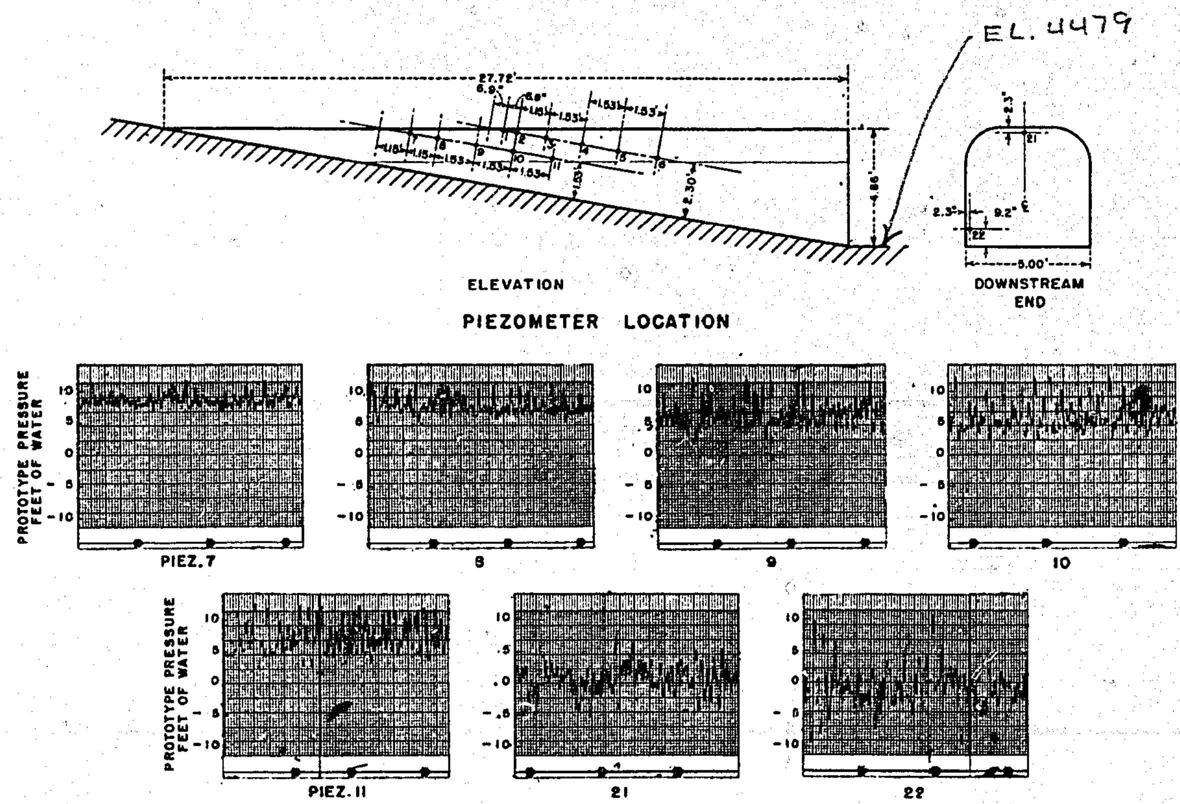
2-12-59 PPK

559



PIEZOMETRIC PRESSURES

A. ORIGINAL DESIGN



PIEZOMETRIC PRESSURES

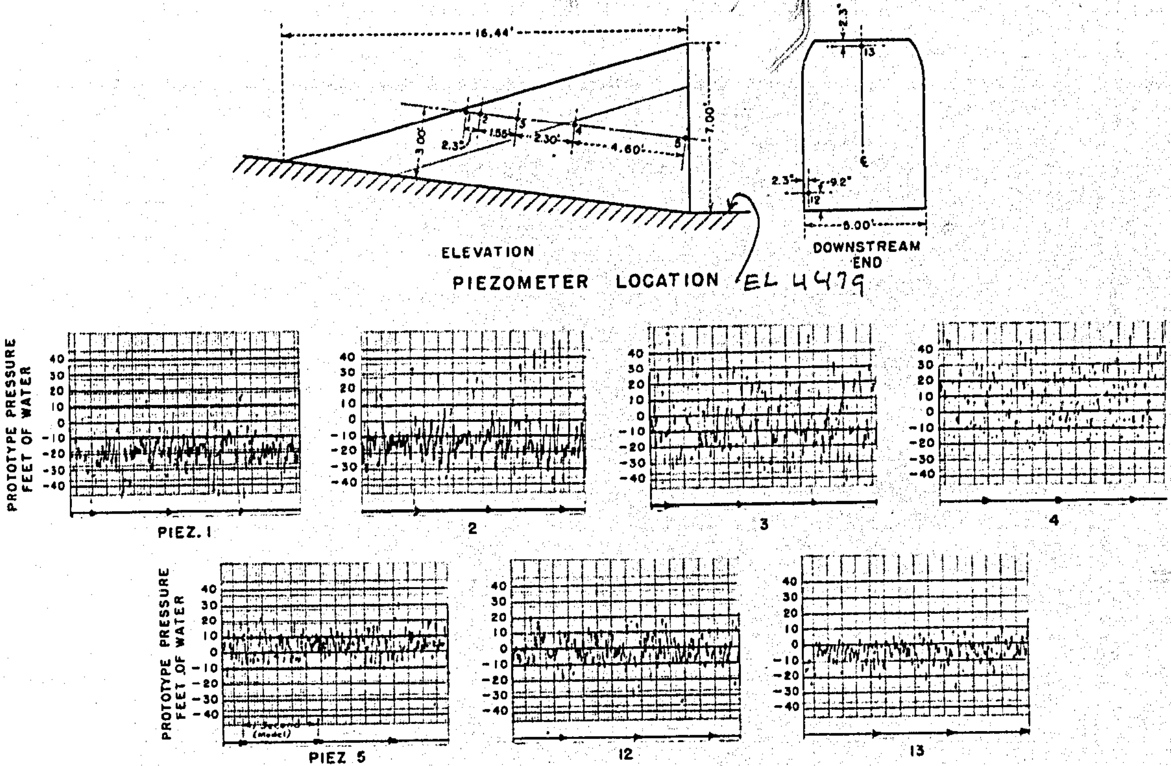
B. RECOMMENDED DESIGN

GLENDO DAM OUTLET WORKS

CHUTE BLOCK PRESSURES

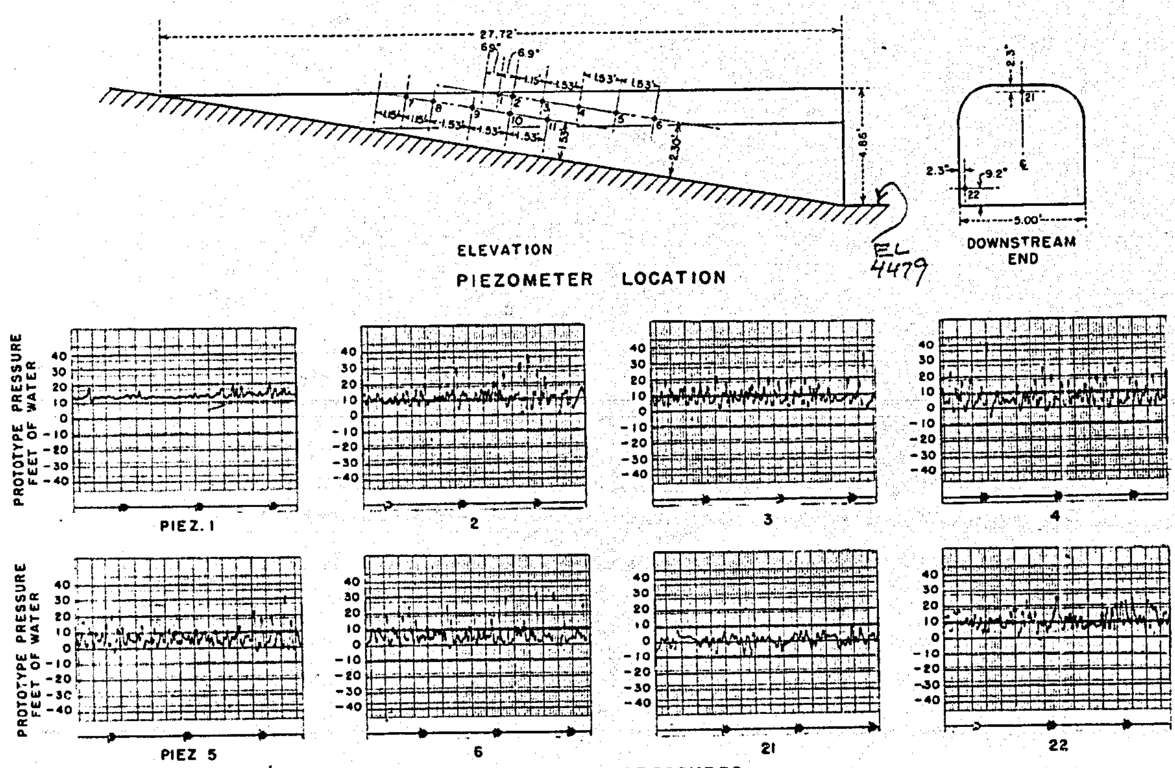
GATE OPENING = 60% Q = 4,500 C.F.S. (2 GATES) TW = 4501.4 (NORMAL)

SCALE MODEL 1:18.4



PIEZOMETRIC PRESSURES

A. ORIGINAL DESIGN



PIEZOMETRIC PRESSURES

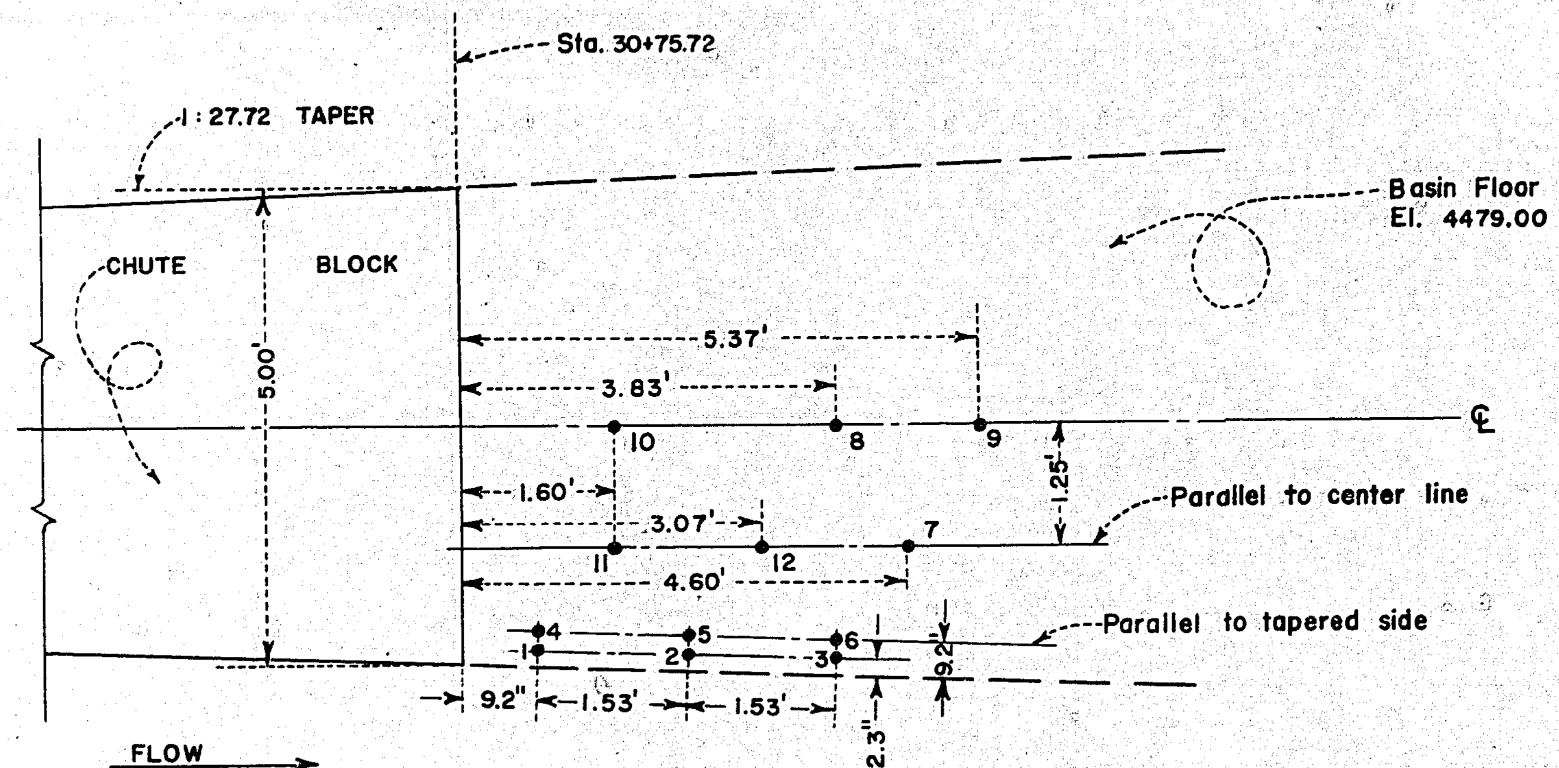
B. RECOMMENDED DESIGN

GLENDO DAM OUTLET WORKS

CHUTE BLOCK PRESSURES

GATE OPENING = 83% Q = 10,000 C.F.S (3 GATES) TW = 4505.2 (NORMAL PLUS 1 1/2 FT.)

SCALE MODEL 1:18.4



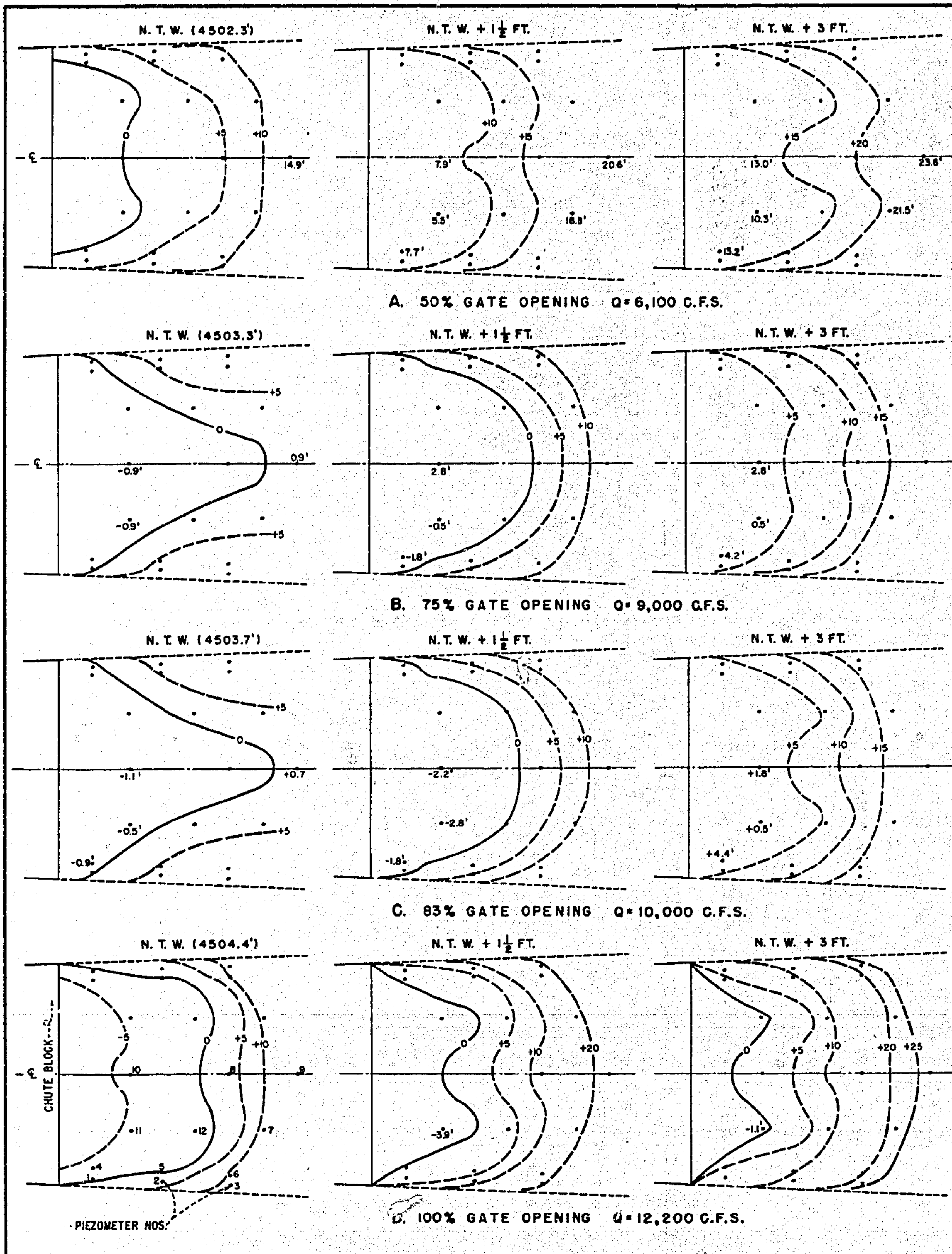
GLENDO DAM OUTLET WORKS

PIEZOMETER LOCATIONS IN BASIN FLOOR DOWNSTREAM FROM CHUTE BLOCK

1: 18.4 SCALE MODEL

559

5-14-59 PPK

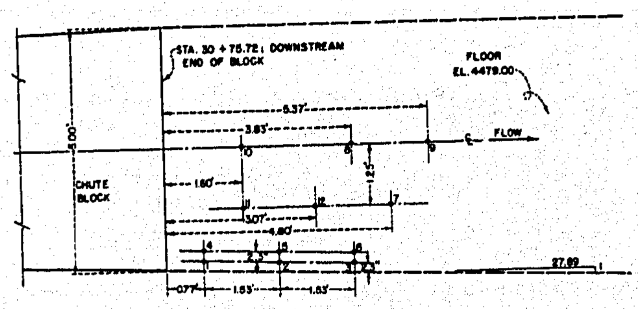


GLENDO DAM OUTLET WORKS

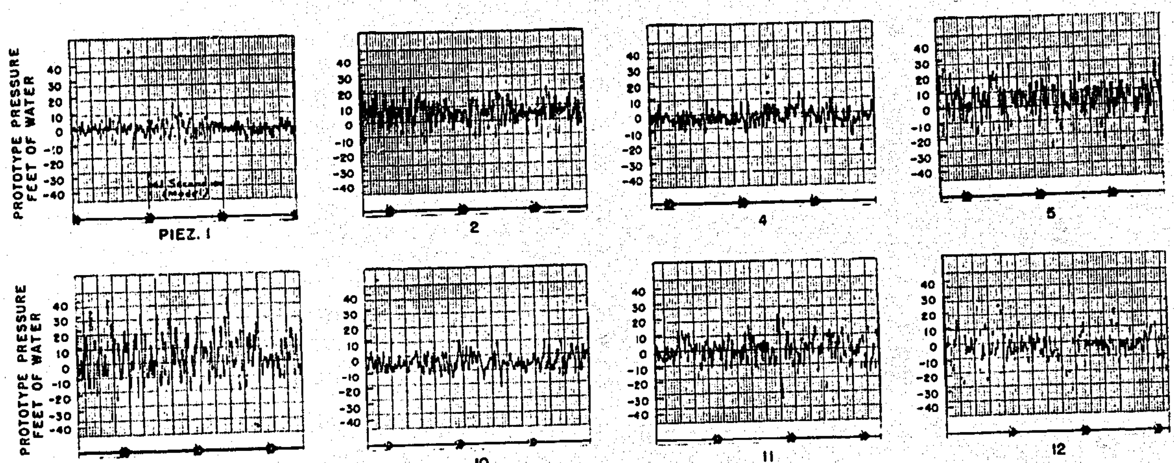
AVERAGE PROTOTYPE FLOOR PRESSURES DOWNSTREAM FROM CHUTE BLOCK NO. 5

AT VARIOUS GATE OPENINGS AND TAILWATERS

1:18.4 SCALE MODEL

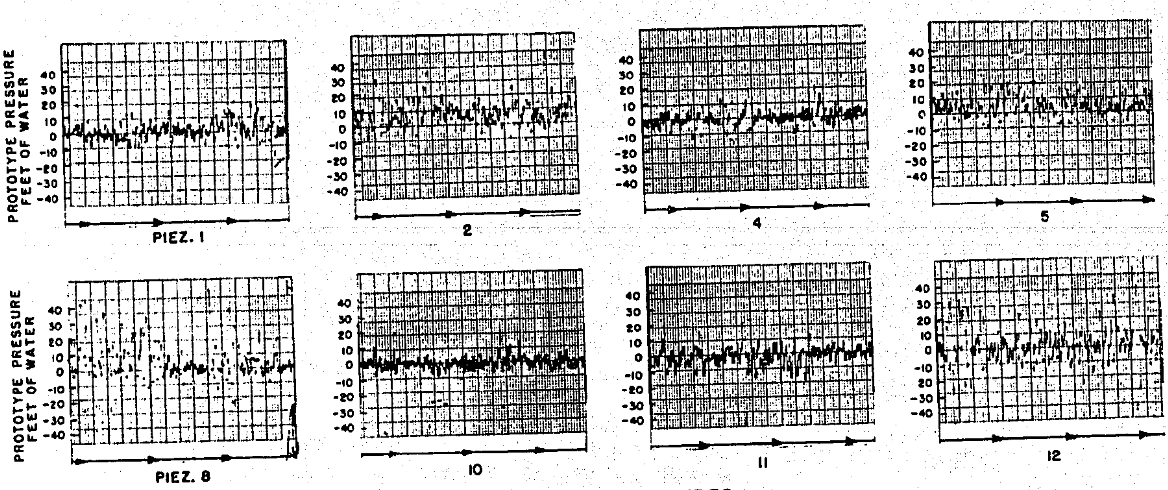


PIEZOMETER LOCATION



PIEZOMETRIC PRESSURES

A. DOWNSTREAM FROM ORIGINAL CHUTE BLOCK



PIEZOMETRIC PRESSURES

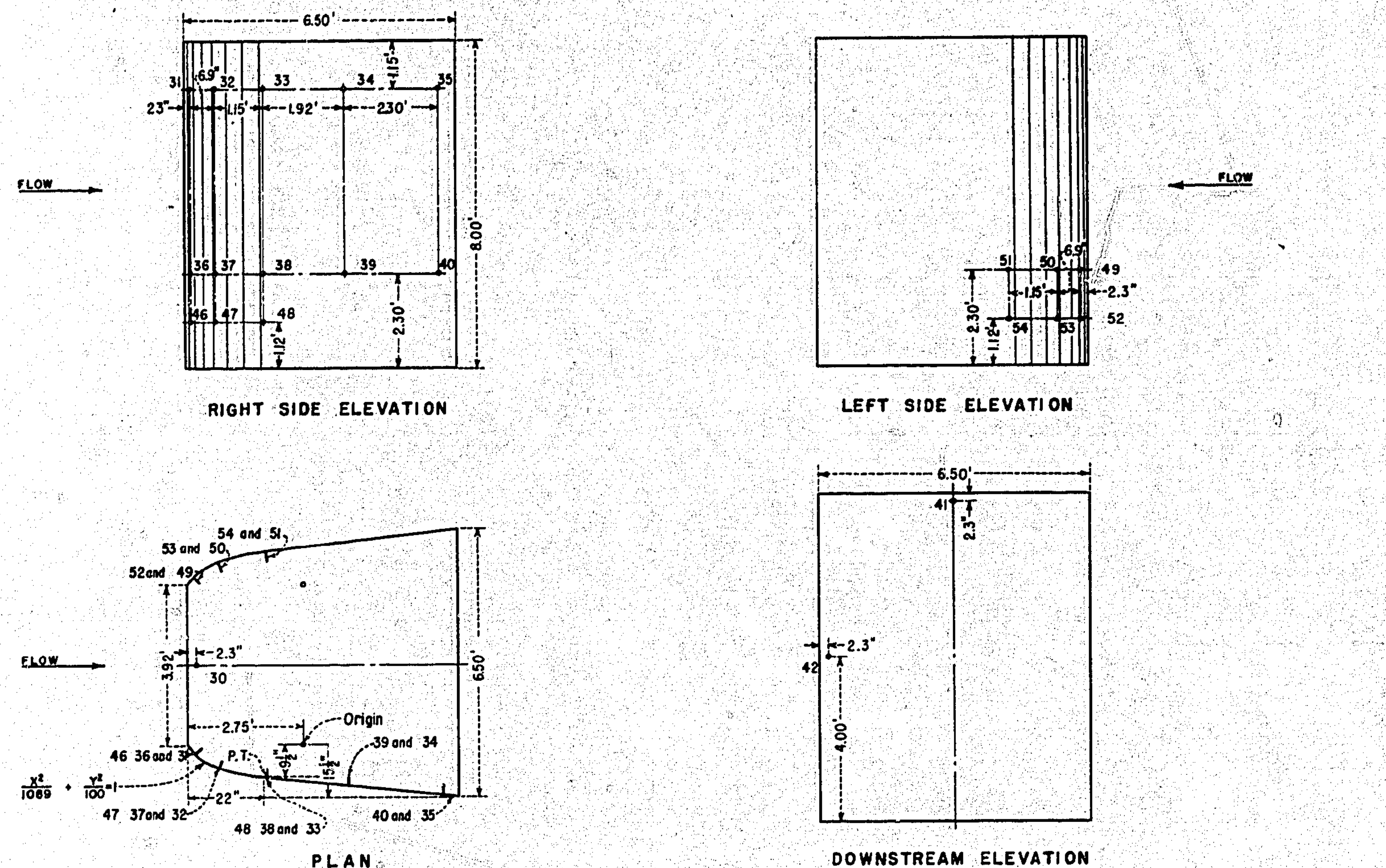
B. DOWNSTREAM FROM RECOMMENDED CHUTE BLOCK

GLENDO DAM OUTLET WORKS

BASIN FLOOR PRESSURES

GATE OPENING = 50% Q = 6,100 C.F.S. (3 GATES) TW = 4502.3 (NORMAL)

SCALE MODEL 1:18.4



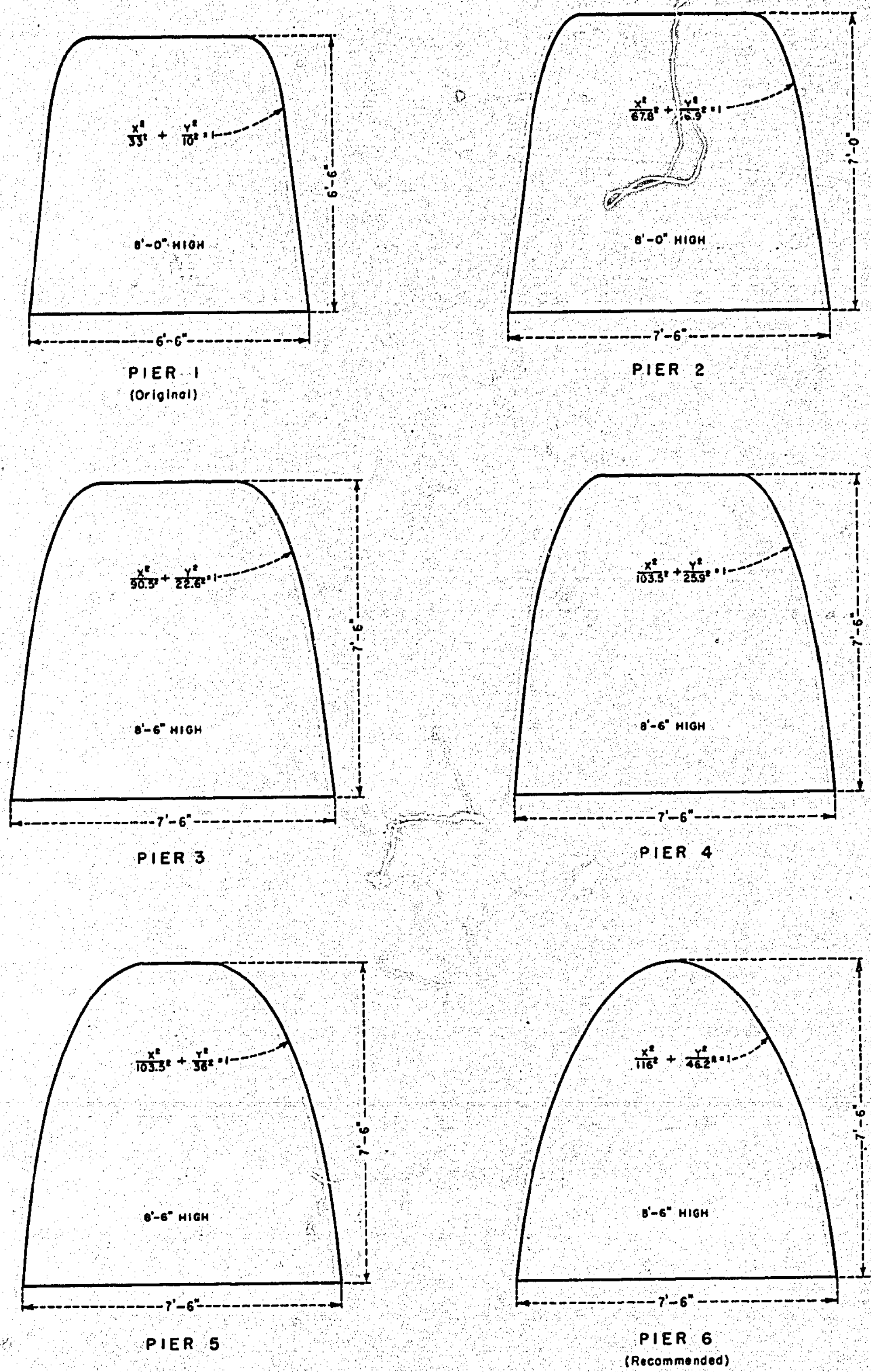
GLENDO DAM OUTLET WORKS

PIEZOMETER LOCATIONS IN ORIGINAL BAFFLE PIER

1:18.4 SCALE MODEL

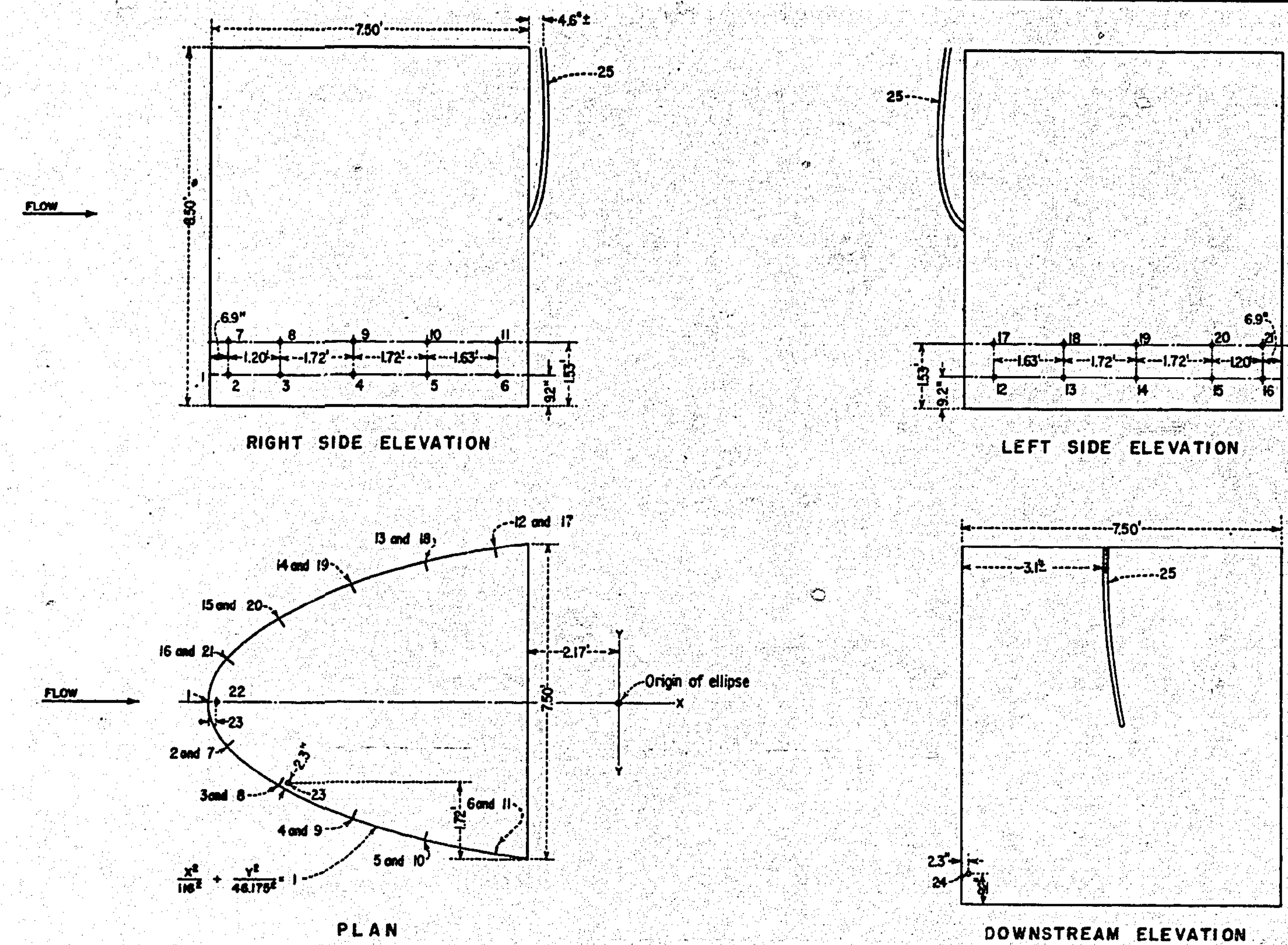
559

8-15-59 PPK



GLENDO DAM OUTLET WORKS
TEST BAFFLE PIER SHAPES
1:18.4 SCALE MODEL

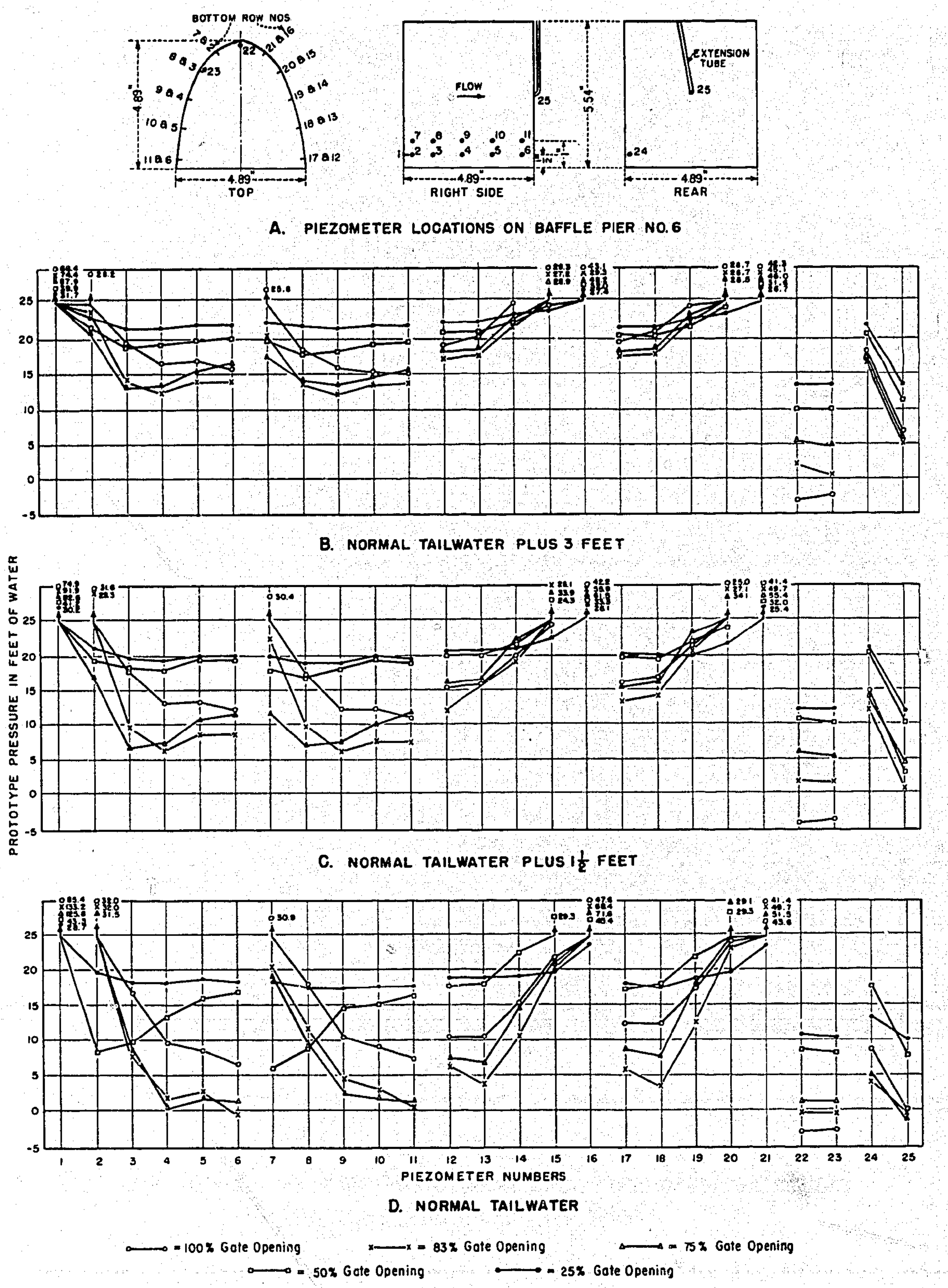
559



GLENDO DAM OUTLET WORKS

PIEZOMETER LOCATIONS IN RECOMMENDED BAFFLE PIER

1:18.4 SCALE MODEL

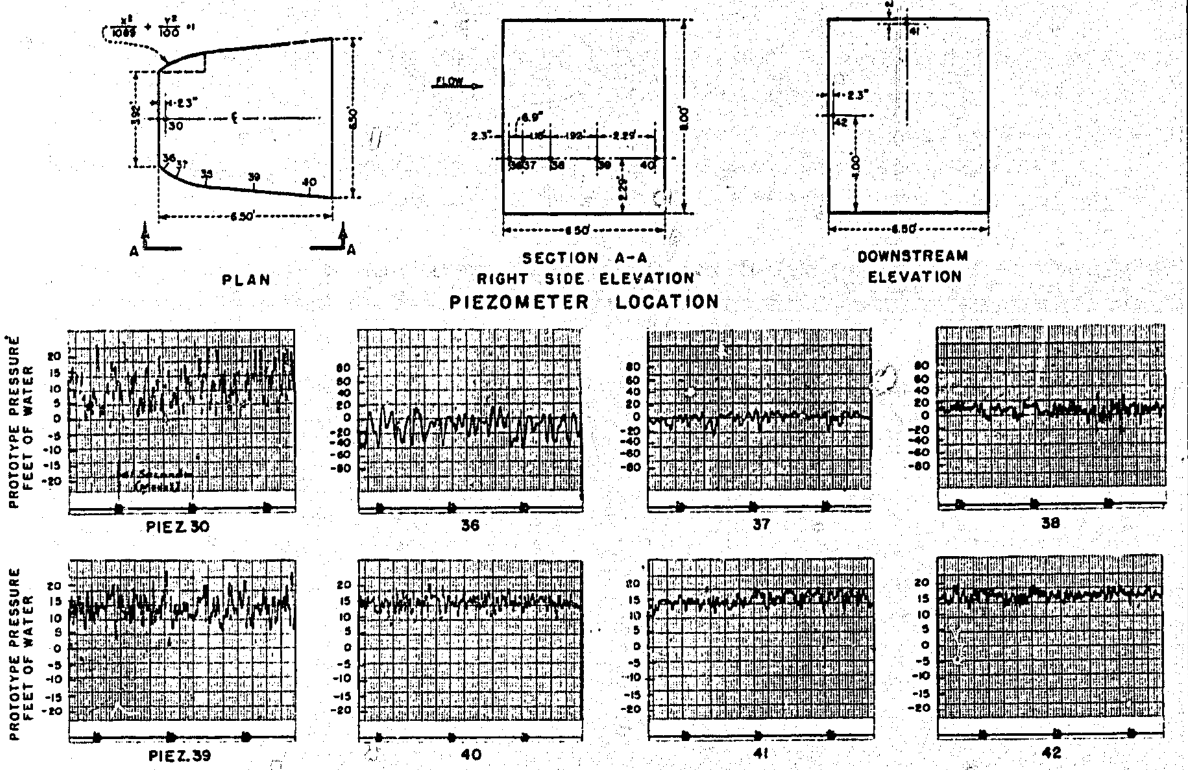


GLENDO DAM OUTLET WORKS

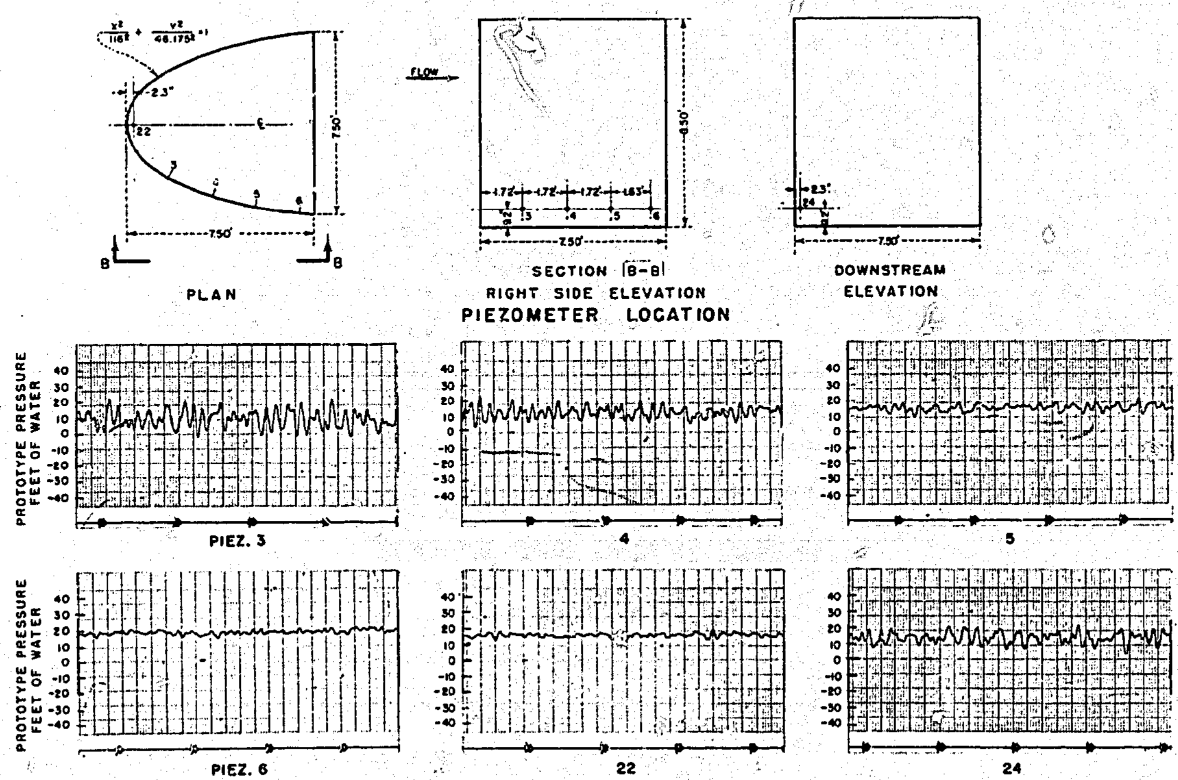
AVERAGE PIEZOMETRIC PRESSURES ON RIGHT BAFFLE PIER NO. 6 (RECOMMENDED)

1:18.4 SCALE MODEL

FIGURE 19
REPORT HYD.- 461

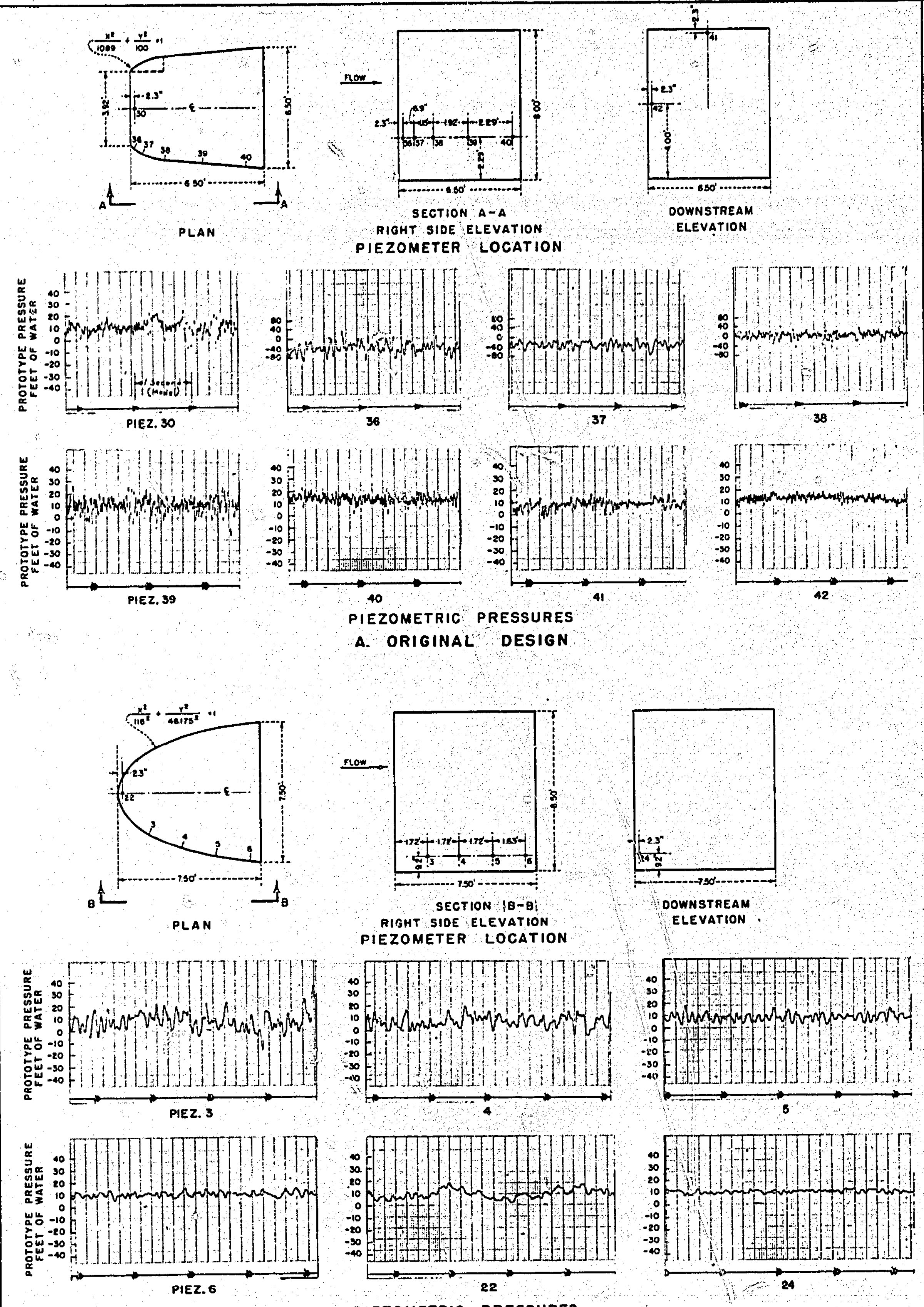


PIEZOMETRIC PRESSURES
A. ORIGINAL DESIGN



PIEZOMETRIC PRESSURES
B. RECOMMENDED DESIGN

GLENDO DAM OUTLET WORKS
BAFFLE PIER PRESSURES
GATF OPENING = 60% Q = 4,500 C.F.S. (2 GATES) TW = 4501.4 (NORMAL)
SCALE MODEL 1:18.4



PIEZOMETRIC PRESSURES
B. RECOMMENDED DESIGN

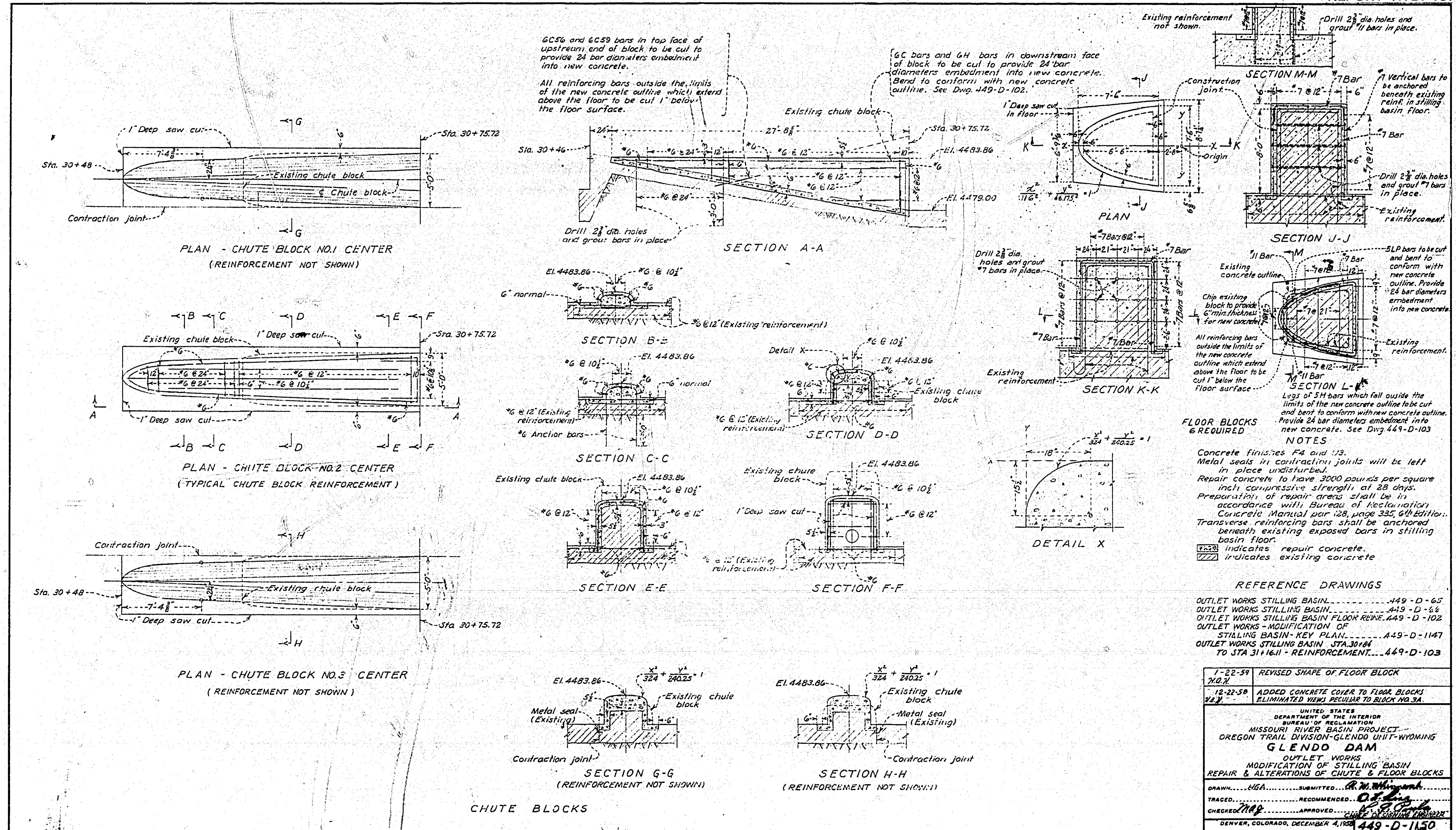
GLENDO DAM OUTLET WORKS

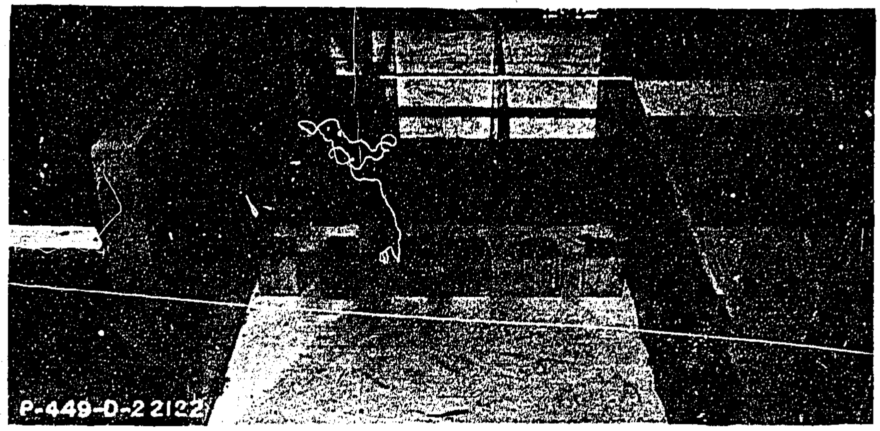
BAFFLE PIER PRESSURES

GATE OPENING = 83% Q = 10,000 C.F.S. (3 GATES) TW = 4505.2 (NORMAL PLUS 1 1/2 FT.)

SCALE MODEL 1:18.4

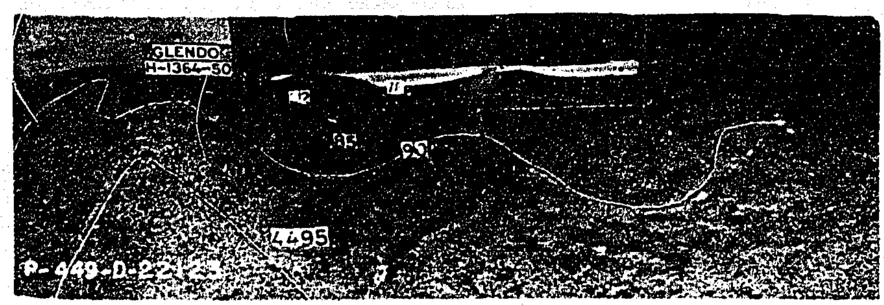
FIGURE 21
REPORT HYD.-461



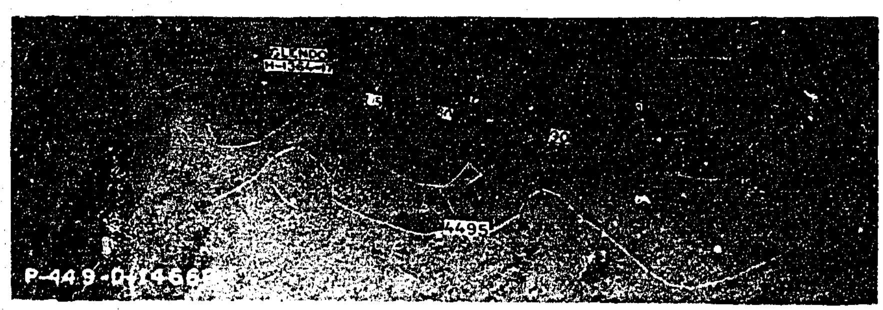


A. The 1:18.4 Model - Original Design

B. Jump Swept from Original Basin
83% gate opening Q=10,000 cfs.
TW=4503.7

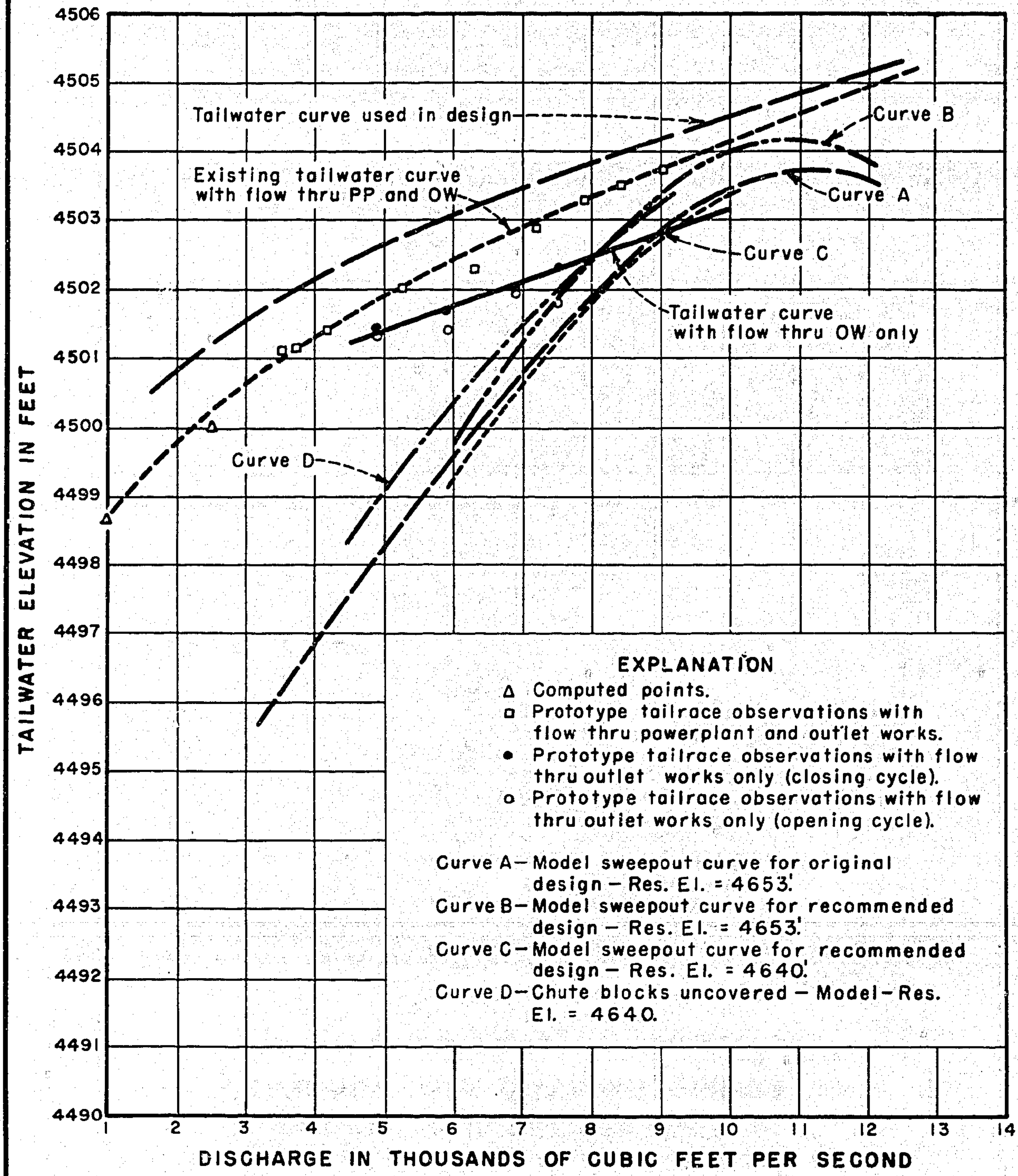


C. Scour pattern in original design after 1-hour operation, at 83% gate opening. Q=10,000 cfs. TW=4505.2'

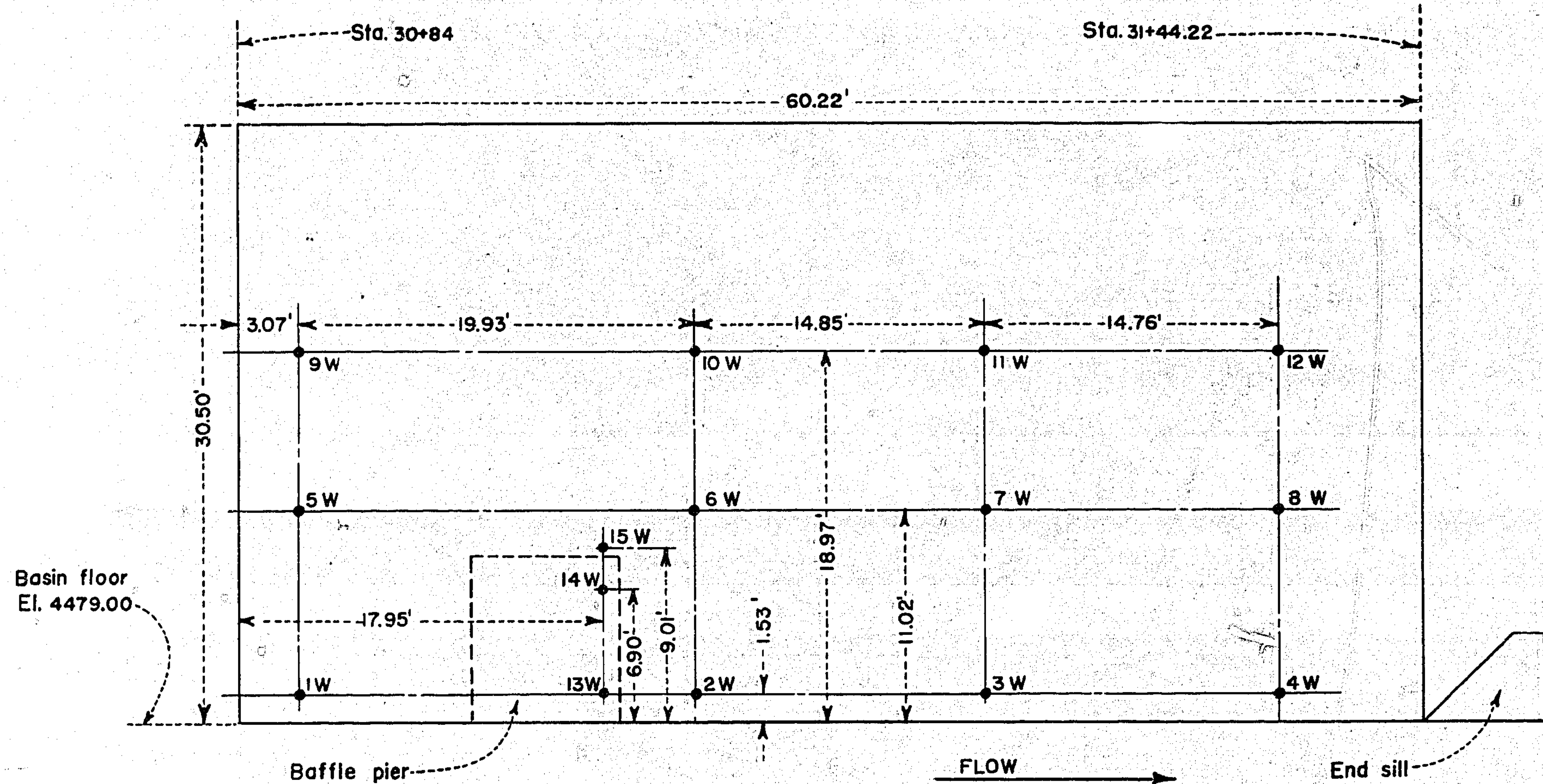


D. Scour pattern in Recommended design after 1-hour operation at 83% gate opening. Q=10,000 cfs. TW=4505.2'

GLENDO DAM OUTLET WORKS
1:18.4 Scale Model



GLENDO DAM OUTLET WORKS
TAILWATER AND SWEEPOUT CURVES
1:18.4 MODEL AND PROTOTYPE OBSERVATIONS



GLENDO DAM OUTLET WORKS
PIEZOMETER LOCATIONS ON SPLITTER WALL EXTENSION
1:18.4 SCALE MODEL

559

5-14-59 PPK

GPO 838400II